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What a Decade of Experiments Reveals about Factors that Influence the Sense of Presence

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March 2006

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IDA Document D-3208
Log: H 05-002013

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Preface

This work was performed under the "ADL Common Framework" task. Technical cognizance for this task is assigned to Dr. Robert Wisher, Office of the Under Secretary of Defense for Personnel and Readiness, Readiness and Training Directorate. The Institute for Defense Analyses (IDA) point of contact (POC) is Dr. Christine Youngblut.

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Executive Summary

The sense of presence, “being there,” is a real phenomenon. The literature contains many anecdotal accounts of how users have reacted to a virtual scene in instinctual ways that suggest they believe, at least for a short time, that virtual events are real. Yet, much remains unknown. Does a strong sense of presence cause users to engage mental models and cognitive processes that they have already developed in a real environment? Will behavior learned in a virtual-world transfer to a corresponding real scenario? These questions remain unanswered. This document reviews what experimental results reveal about technical factors and task characteristics that may influence the sense of presence.

For the discussions here, *presence* is loosely defined as the subjective experience of being in a place or environment, even when one is physically situated in another place or environment. *Co-presence*, then, is the experience of being with another person (actual or computer generated) in a place or environment such that he has access to that person and, conversely, that person has access to him. This is different from *social presence*, which goes a step further to address social psychological ideas of personal interaction and implies some awareness of a collocated person’s intelligence and intentions. Factors that may be related to co-presence and social presence have been examined less than those that may influence presence.

The purpose of this document is to provide guidance about factors that have a good probability of manipulating presence, to give a feel for the scope of experimentation that has been performed, and to facilitate the identification of critical gaps where future research may make the most difference. It takes high-level look at the results of many hours of hard work performed by a large number of researchers.

What can be learned from this body of work? In many cases, the interfaces, virtual worlds, and experimental tasks that have been used in experiments are not representative of likely practical uses of virtual environment (VE) technology. This was for good reasons, usually to try and avoid factors that might confound results. So, while past research has provided some indications of technical and task characteristics whose manipulation may increase or decrease a user’s sense of presence, the findings must be applied cautiously.

Also, presence is usually reported in terms of questionnaire scores that only have a relative value for comparing scores when some characteristic has changed. The meaning of a score in

absolute terms is unknown. Even though the characteristics of some interface devices will improve with advances in the underlying technologies, rapid near-term improvements are not foreseen. Meanwhile, understanding how the constraints imposed by VE technology may affect presence will continue to be important.

An important point has been made by more than one researcher: When it comes to presence, just adding "more textures, more resolution, or more …" does not necessarily lead to continual increases in presence. Instead, a consistent level of realism has to be presented since mismatches in realism seem to cause a conflict that impedes users' sense of presence. In addition, there may be a plateau effect, beyond which it is not cost effective to reach for higher levels of presence, although there are no data on this yet.

Progress in this area needs a better understanding of the presence construct and how to measure it and also a better understanding of how presence is related to the desired outcomes of a virtual experience.

What a Decade of Experiments Reveals
About Factors That Influence the Sense of Presence

The sense of presence, “being there,” is a real phenomenon. The literature contains many anecdotal accounts of how users have reacted to a virtual scene in instinctual ways that suggest they believe, at least for a short time, that virtual events are real. Quite recently, Schuemie et al. (2005) found that the extreme fear experienced by some participants in a virtual world prevents them from completing the experimental scenarios. Yet, much remains unknown. Does a strong sense of presence cause users to engage mental models and cognitive processes that they have already developed in a real environment? Will behavior learned in a virtual-world transfer to a corresponding real scenario? These questions remain unanswered. This document reviews what experimental results reveal about technical factors and task characteristics that may influence the sense of presence.

For the discussions here, *presence* is loosely defined as the subjective experience of being in a place or environment, even when one is physically situated in another place or environment. *Co-presence*, then, is the experience of being with another person (actual or computer generated) in a place or environment such that he has access to that person and, conversely, that person has access to him. This is different from *social presence*, which goes a step further to address social psychological ideas of personal interaction and implies some awareness of a collocated person’s intelligence and intentions.

The purpose of this document is (1) to provide guidance about factors that have a good probability of manipulating presence, (2) to give a feel for the scope of experimentation that has been performed, and (3) to facilitate the identification of critical gaps where future research may make the most difference.

It is not possible to discuss the results of all 174 experiments that have examined presence. Instead, the approach taken is to discuss those experiments that have been replicated (more or less) and the factors that have shown consistent results across studies. This is not meant to minimize the importance of nonreplicated experiments that have used good experimental practices. These experiments can provide good direction for those interested in systems highly similar to the ones used in the study and also may provide insight into differences that can be expected under other circumstances. However, more confidence can be placed in results that are confirmed

in replicated experiments. Experiments that have found similar results using a range of interface devices, virtual worlds, and experimental tasks may indicate that some of their results can be generalized; however, there are no guarantees. There are bound to be exceptions over time (e.g., a new experiment that finds a different effect for some characteristic). Such exceptions need not invalidate the usefulness of prior work. In fact, they may help to define the circumstances under which a particular finding does and does not apply.

Before looking at experimental results, a few words of caution are appropriate. There are hazards in comparing findings across experiments. Most researchers have used questionnaires to assess presence, and these questionnaires often differ widely in orientation and scope. The experiments have employed a wide range of virtual worlds. Some are highly detailed representations of real environments, while others present a single object or avatar in an open space. Some virtual worlds were viewed immersively, and others were viewed on a desktop monitor. The levels and modes of supported interaction and the devices used to achieve interaction vary. There are also important differences in experimental protocols, including, for example, participant characteristics and whether presence data were captured while a participant was still in a virtual world or after he had completed that stage of an experiment. Finally, some of these experiments were primarily designed to examine other issues, and presence data may not have been fully examined and reported. Although experimental data show a statistically significant effect of certain factors on the sense of presence, it is also important to note that no data demonstrate whether any effect is a causal one. This means that some minimal knowledge about each experiment is necessary to interpret their results correctly. To aid this understanding, the Appendix to this document contains brief summaries of the full set of 174 experiments.

While the focus of this document is the experience of presence in computer-generated virtual worlds, a small proportion (less than 4 percent) of the experiments used different media. For example, in trying to understand the importance of creating expressive behaviors for avatars, Garau et al. (2001) conducted an experiment using video monitors so that gaze behavior would be isolated from any other factors, such as spatial, gestural, or postural cues that might have confounded results. Even so, the intent is to include only those experiments whose results are applicable to computer-generated virtual worlds.

This document starts with a brief description of the different presence measures used in the experiments discussed here. Throughout, when papers and reports discuss more than one experiment, the reference to a particular experiment is distinguished as, for example, Snow (1996 (1)) or Snow (1996 (2)). Also, to accommodate the restricted space available, all references in the tables list only the first author.

1. Presence Measures

To interpret the results of the experiments discussed in this document, knowing something about the presence measures that were used is necessary. Without going into details, this section attempts a broad characterization of the different presence measures.

Most of the experiments used self-report questionnaires to assess the sense of presence experienced by experiment participants. The most widely used questionnaire was the Slater-Usoh-Steed (SUS) Questionnaire. Developed by researchers at the University College London (UCL), it usually consists of six questions based on (a) the sense of “being there” in a virtual world as compared with being in a place in the real world, (b) the extent to which there are times when the virtual world became the dominant reality, and (c) the extent to which a user remembers the virtual world as a place visited rather than one in which he saw computer-generated images. The next most common questionnaire is that developed by B.G. Witmer and M.J. Singer at the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI), usually referred to as the Presence Questionnaire (PQ). It was designed to address issues of both the immersion provided by the interface to a virtual world and a user’s involvement. It consists of 32 items, organized into 6 subscales: Involved/Control, Natural, Interface Quality, Auditory, Haptic, and Resolution. Many researchers used questionnaires based on the SUS Questionnaire or the PQ or selected items from both. The focus of these questionnaires can be indicated by their positions on a scale with the SUS Questionnaire and the PQ as the endpoints, as shown in Figure 1.

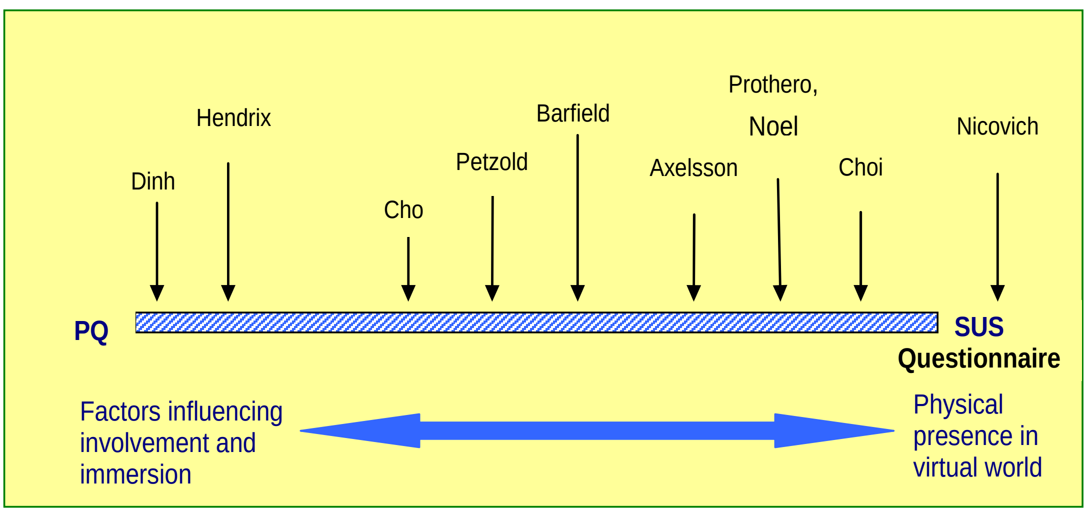

Figure 1. Questionnaires Related to the PQ and SUS Questionnaires

Several other questionnaires were also used. The 14-item Igroup Presence Questionnaire (IPQ) is based on the belief that presence develops from the construction of a spatial-functional

mental model of a virtual world. The IPQ queries users' sense of spatial presence, involvement, and reality in a virtual world. The Independent Television Commission-Sense of Presence Inventory (ITC-SOPI) questionnaire focuses more on the physical sense of presence and is intended for use with a variety of media, not just virtual worlds. It contains 44 items organized into 4 subscales: Sense of Physical Space, Engagement, Ecological Validity, and Negative Effects. The Swedish User-Viewer Presence Questionnaire (SVUP) also focuses on a physical sense of presence. Its full form consists of 150 items, although current experiments have used only a subset of these items to query a user's ability to interact with a virtual world and determine his awareness of external factors, enjoyment, and simulation sickness in addition to asking more directly about presence. The Web site http://www.presence-research.org/Questionnaires.html contains more details about these questionnaires and the PQ and SUS Questionnaire. The final questionnaire used in the experiments discussed here is the UCL Questionnaire. This is an extended version of the SUS Questionnaire, with 13 items organized into 3 subscales: Reported Presence, Reported Behavioral Presence, and Reported Ease of Locomotion.

Several other types of presence measures were used. Two methods are based on magnitude estimation, a measurement method that has been used in human-related research for many years. For this method, a user is presented with a series of stimuli and asked to assign a number to each stimulus based on his subjective impression of its intensity. Snow (1996) uses a form of free-modulus magnitude estimation that allows the user to assign any appropriate value to the first stimulus and then assign numbers to successive stimuli with respect to the first. The method of paired comparison, used by Welch et al. (1996), asks a participant to make a comparison between stimuli, rather than comparing them to some modulus. Participants are also asked to provide a rating of the size of the perceived difference between the stimuli. Finally, there are simple rating scales, where a user rates his sense of presence numerically or on a visual-analog scale.

2. Findings for Presence

2.1 Technical Characteristics That Affect Presence

Researchers have investigated the relationship of nearly 30 technical characteristics with the sense of presence experienced in virtual worlds. Table 1 lists these characteristics. In several cases, researchers have repeated experiments. These replications provide some of the best data on the relationships between particular technical factors and presence. They are discussed next (see Section 2.1.1). After that, those cases where several experiments have found consistent results for the same technical characteristic are discussed (see Section 2.1.2).

Table 1. Technical Characteristics Examined for Presence

Audio	Level of equipment
Avatars	User movement
Collision response	Navigation
Color	Olfactory cues
Detail (level of)	Presence manipulation
Presentation quality	Scene realism
Dynamic shadows	Self-representation
Field of view	Social presence manipulation
Frame rate	Stacking depth
Haptic cues	Stereoscopy
Head-tracking	Tactile cues
Image motion	Texture mapping
Interaction (level of)	Update rate
Latency	Visual display

2.1.1 Replications

While most experiments differ in some small way, experiments similar enough to treat as replications have looked at several aspects of visual displays, the use of audio cues, image motion, navigation methods, presentation quality, scene realism, and the use of avatars to provide a user with some form of self-representation in a virtual world. Table 2 identifies these experiments, with the presence measures that each used.

Audio

The use of audio cues to promote a sense of presence in virtual environments (VEs) has been investigated in 10 experiments. The specific features examined have ranged from different audio mixes to the use of still or moving sound sources. Hendrix and Barfield (1996b) hypothesized that using spatialized audio, as opposed to nonspatialized audio, would provide sufficient auditory cues so that the sound sources would be externalized, resulting in a greater sense of presence and realism. They conducted two experiments to investigate this. Spatialized sounds were generated using a Crystal River Engineering Beechtron audio spatializer card and delivered over orthodynamic head phones. The actual sounds were a live, continuous broadcast from a progressive light rock radio station and a repeated, discrete recording of a monetary exchange with a vending machine. These sounds were not correlated to any participant activities in the virtual worlds. The experiments were conducted in a 10 × 10 meter virtual room with a checkerboard patterned floor and objects such as tables and chairs, a bookshelf, a soda machine, a photocopier machine, and paintings. The virtual room was viewed on a 6 × 8 foot rear-projection screen, using shutter glasses to achieve stereo vision. Participants navigated around several different versions of the virtual room to become familiar with these different versions before answering a presence questionnaire that had been made available to them previously. One experiment compared spatialized environmental sounds (uncorrelated with any participant actions) against a condition with no sounds (see Hendrix and Barfield (1996b (1))). The second experiment compared spatialized and nonspatialized sounds (see Hendrix and Barfield (1996b (2))). These two experiments used presence questionnaires of slightly different length but identical in all other respects. Both

Table 2. Technical Characteristics Examined in Replicated Experiments for Presence

Factor		Conditions	Significant Relationship (Condition(s) Yielding Most Presence)	Presence Measure	Experiment Reference
Audio cues	# sources	Three, one	–	Magnitude estimation	(Larsson 2004)
		Three, one	–	Rating scale	(Väljamae 2004)
	Source rotation	60, 40, 20º per sec	60º per sec (3 sources)	Magnitude estimation	(Larsson 2004)
		60º, 20º per sec	–	Rating scale	(Väljamae 2004)
	Spatialized	Spatialized, nonspatialized	Spatialized	6-item questionnaire	(Hendrix 1996b (2))
		Spatialized, no audio	Spatialized	6-item questionnaire	(Hendrix 1996b (1))
Image motion		Car rally video, still frame	Car rally video	Rating scale	(Freeman 2000)
		Car rally video, still frame	Car rally video	Rating scale	(Ijsselsteijn 2001a)
Foreground/background		As foreground, as background	As background	Prothero's questionnaire	(Prothero 1995a (1) (2))
Navigation		Walking-in-place, 3-D mouse	Walking-in-place[1]	3-item SUS Questionnaire	(Slater 1995a)
		Walking-in-place, push-button-fly	Walking-in-place[1]	7-item SUS Questionnaire	(Usoh 1999)
Presentation quality		High, low, text	High > low > text	PQ, 6-item SUS Questionnaire	(Nuñez 2003a)
		High, low	High	PQ, 6-item SUS Questionnaire	(Nuñez 2003b)
Scene realism		High scene detail, low scene detail	High scene detail	Paired comparison	(Welch 1996 (1) (2))
Self-representation		Virtual body, virtual hand	–	PQ	(Allen 2001)
		Virtual body, pointer	–	PQ	(Singer 1998)
Stereoscopy		Present, absent	Present	Rating scale	(Freeman 2000)
		Present, absent	Present	Rating scale	(Ijsselsteijn 2001a)
Update rate		20, 15, 10 Hz	20, 15 Hz	18-item questionnaire	(Barfield 1998)
		25, 20, 15, 10, 5 Hz	25, 20 Hz	13-item questionnaire	(Barfield 1995)
Visual display		5-sided Cave, monitor	Cave	2-, 1-item questionnaires	(Axelsson 2001)
		5-sided Cave, monitor	Cave	2-item questionnaire	(Wideström 2000)
		5-sided Cave, 4-sided Cave, monitor	5-, 4-sided Cave	2-, 1-item questionnaires	(Schroeder 2001)
		5-sided Cave, 4-sided Cave, HMD, monitor	5- ,4-sided Cave, HMD	2-item questionnaire	(Heldal 2005)
		HMD stereo/mono, HMD mono mouse, monitor	–	6-item SUS Questionnaire	(Mania 2003)
		HMD stereo/mono, HMD mono mouse, monitor	–	SUS Questionnaire	(Mania 2001b)
		HMD, monitor	–	2-item SUS Questionnaire	(Slater 2000b)
		HMD, monitor	–	SUS Questionnaire	(Steed 1999)
		HMD, monitor	–	SUS Questionnaire	(Tromp, 1998 (2))

1 For participants who had a strong association with their virtual body.

found that participants gave significantly higher ratings for presence when spatialized audio was provided. In the second experiment, participants also reported that spatialized sounds increased the fidelity of their interactions with sounds. In both cases, Hendrix and Barfield note that the addition of spatialized sound did not influence participants' ratings of realism of the virtual worlds. They suggest this may have been because the sounds had no meaning in the context of the rooms visited or because the participants focused on the visual aspects of the virtual worlds.

A group of researchers has investigated the auditory illusion of self-motion (vection) as part of the European Perceptually Oriented Ego-Motion Simulation (POEMS) project. Based on ideas of ecological acoustics, they expected that characteristics of a sound source would be important in inducing vection. In particular, they investigated the role of a rotating sound field, using several concurrent sound sources, and acoustic rendering quality (see Larsson et al. (2004)). The stimuli were binaural simulations of a virtual listener in the marketplace in Tübingen, Germany. This listener stood in one place and rotated a given number of times. The sounds were generated using the Walkthrough Convolver and presented using circumaural headphones. Trials were conducted in a semi-anechoic room. In addition to collecting feedback about any sensations of vection, the researchers asked participants to rate their sense of presence using a magnitude estimation measure. For single sounds, only input source had a significant relationship with presence, with more presence reported for still sounds than for moving or artificial sounds. There was a significant interaction between sound source and auralization quality such that both the still and moving sound sources were given higher ratings in the marketplace condition. For multiple sound sources, the sound source, velocity, and quality had a significant effect, with greater presence reported for still and moving sources, the faster turn velocity of 60°/s, and the marketplace environment, respectively. This first experiment used generic Head-Related Transfer Functions (HRTFs) to generate the spatialized sounds. Since these generic HRTFs can cause distortions because of mismatches with the auditory characteristics of participant individuals, the experiment was repeated adding individualized HRTFs and using only still sounds (see Väljamae (2004)). The use of individualized HRTFs was associated with significantly increased presence. The differences related to turn velocity and sound quality previously found for multiple sound sources were not present. The researchers do not speculate on a reason for this. However, the only relevant change was the introduction of individualized HRTFs, and the researchers do note some problems in the rapid preparation of these HRTFs that may have influenced participants' ratings about vection. Both experiments did find that the number of sound sources (three or one) had no direct relationship with presence.

Image motion

Depending on the degree of realism required, representing moving objects as simple as a bouncing ball can be computationally expensive. Sometimes, object motion is required for task performance, but, if not, does including movement increase users' sense of presence? Two experiments that investigated the value of postural response as a behavioral indicator of presence provide some useful feedback. They used video stimuli instead of a computer-generated virtual world, but the results are still useful with respect to VE systems. Described by the researchers as replications, these experiments were similar in all respects except for the visual display device used.

The stimuli were (a) a 100-second excerpt from a rally car sequence filmed for the ACTS MIRAGE *Eye to Eye* documentary using a camera mounted on a car hood and (b) a still frame taken from the same footage, with a camera placed by the side of the rally track before the car drove by. The moving video was accompanied by a nondirectional audio track consisting of sounds from a car engine, gear changes, and the clattering from stones hitting underside of the car. The same audio track with a lower sound intensity (as though the car was approaching) was used with the still frame. In the experiment reported by Freeman et al. (2000), participants viewed the scene on a 20-inch stereoscopic monitor using polarized glasses. In the replication, reported by Ijsselsteijn et al. (2001a), twin projectors were used to illuminate a curved 1.9×1.45 meter projection screen and, again, participants wore polarized glasses to achieve stereo viewing. The results of the experiments were the same. As expected, image motion was associated with a significant increase in participants' sense of presence. These experiments also examined the effect of image motion on the illusion of vection. Again, results were consistent. As expected, viewing a moving image was associated with significantly higher reports of vection than when viewing a still image.

As yet, there seem to be no data on what degree, or kind, of motion is most relevant for presence. Only one experiment has examined the importance of physical realism. Using different levels of elasticity, friction, and shape models for collision detection in a game on pin bowling, Uno and Slater (1997) reported that friction's effect on presence depended on the shape realism and that elasticity had no measurable effect.

Foreground vs. background occlusion

Prothero et al. (1995a), as part of their investigation into the possible relationship between the visual illusion of self-motion and presence and, in particular, the effect of relative motion between the self and the perceived background, hypothesized that users form a reference

frame. They call the frame that an observer takes to be stationary the *rest frame*. This hypothesis predicts that for the same field of view (FOV), the sense of presence in a virtual world will be enhanced when the user believes that the FOV restriction is occurring in the foreground. They conducted an experiment to test this hypothesis using a Division, Ltd. dVisor head-mounted display (HMD) with 40° × 105° FOV and an eye mask that restricted foreground occlusion to 40° and the peripheral occlusion to 60°. The participants also viewed the virtual world when a paper mask was placed over the HMD screens (i.e., further away from their eyes). The virtual world used in the experiment was Division, Ltd's SharkWorld, and participants had to catch sharks using a virtual net. Prothero et al. found a significant difference for the placement of the occlusion, with participants reporting higher presence for the foreground eye masking. They repeated the experiment using a double-bind design for additional reliability and found the same results. The researchers did have problems in finding supporting data using a computer-generated electronic mask (again, effectively, a background occlusion) but ascribe this to difficulties they encountered with another virtual world that was being used. If the rest frame hypothesis holds in other circumstances, it establishes a relationship between vection and presence that could be manipulated to increase the sense of presence that users experience. For example, moving the boundary of the scene forward should increase the sense of presence, and moving it backward should decrease the sense of presence.

Navigation

Naturalistic navigation through large virtual worlds has always posed a problem. Without a large-area tracker, navigating is difficult in any area except a small virtual room where a user can move normally. Considerable effort has been invested in developing special locomotion devices (e.g., an omni-directional treadmill) and novel software-supported interaction techniques and navigation aids. One of the most conceptually simple approaches is to have the user direct his movement through a virtual world by walking-in-place. Sensors capture this action and feed the results to a neural net that then directs the user's viewpoint through the virtual world in the direction of his gaze. Activities such as climbing steps and crawling still require additional input using gestures, but this approach precludes the need for expensive equipment that can pose safety hazards.

Researchers at UCL have examined the relationship that walking-in-place, as opposed to more traditional navigation techniques, may have with presence. The first experiment (see Slater et al. (1995a)) compared walking-in-place with the use of a three-dimensional (3-D) mouse. Participants used an HMD to view the virtual world and were represented in the virtual world by simple, block-like avatars that were mapped to participant movements by head and hand tracking.

The experimental task was to pick up an object in a corridor and take it into a room where a narrow ledge surrounded a 6-meter chasm. The object had to be placed on a chair on the far side of the chasm from where the participants entered the room. For participants who had a strong association with their virtual body, the researchers report that those who navigated by walking-in-place gave significantly higher ratings for presence than participants who used the 3-D mouse. These self-reports were supported by behavioral data, in that participants who walked-in-place were statistically less likely to walk out over the representation of the chasm.

An extension to this experiment was conducted to determine whether the results held, given recent advances in hardware and software technology (see Usoh et al. (1999)). Large-area tracking was used, which allowed the effects of walking-in-place and actual walking and the effects of a using a modified joystick to be compared. Also, a more detailed and realistic avatar was used. With respect to walking-in-place, the results were the same. For participants who had a strong association with their virtual self-representation, walking-in-place was associated with significantly more presence than using the joystick. Of course, participants in the real walking condition reported the most presence.

The next section (see Section 2.1.2) describes an additional experiment that provides supporting data on the effect of walking-in-place on the sense of presence.

Presentation quality

Nuñez and Blake have reported on two experiments that shared several similarities in examining the potential relationship between presentation quality and the sense of presence. In both experiments, participants explored a virtual ancient monastery under one of two graphics conditions. These conditions used the same resolution (640 × 480 × 16), but one included textures, radiosity, and sound, whereas the second used flat, shaded polygons and no sound. One experiment (Nuñez and Blake, 2003a) had a third condition: a text-based representation of the monastery supported by low-resolution (280 × 100 × 8) still images. In the second experiment (Nuñez and Blake, 2003b), participants performed two trials. One was in the monastery, and the second was in a virtual contemporary hospital. This second experiment also sought to investigate whether developing a sense of presence is a constructive process that depends on more than sensory input. Accordingly, participants were given related or unrelated priming materials to read before their virtual experience. In both experiments, participants were tasked to search for 20 boxes placed throughout the buildings.

These experiments used both the Witmer-Singer PQ and the SUS Questionnaire to collect presence data. In both experiments, scores for the two questionnaires distinguished between the

audio/visual conditions, with significantly higher presence scores given for the condition with textures, radiosity, and spatialized sound. In the first experiment, however, only the Witmer-Singer PQ distinguished between the low-presentation-quality audio/visual condition and the text-based version. These two questionnaires were developed from different views of presence, so this lack of consistency between their results is not too surprising. Nuñez and Blake stress that the noteworthy issue is the difference in the mean presence scores for the high graphics and text-based conditions. They calculate an average per-item difference of 16 percent for the PQ and 8 percent for the SUS Questionnaire—a difference that is statistically significant but of small magnitude. On this basis, they say that the designer of a VE can expect the sense of presence to be lower in a text-based world than in a comparable graphics-based world—but only by less than 20 percent. However, until there is a better understanding of the influence of presence on task behavior or other outcomes, whether this 20 percent is important can probably only be empirically determined on a case-by-case basis.

Scene realism

Achieving a high degree of scene realism can be a slow and expensive process. Collecting large amounts of data from a real environment and building a high degree of detail into a virtual world may be necessary. Some types of realism, such as weather effects, require massive computations that are still challenging to perform in real time. As with many other technological characteristics, the question becomes "How much is enough?"

Welch et al. (1996) have considered scene realism in the context of a driving task. Using a within-subjects experimental design, participants played the role of both a car driver and a passenger. When functioning as a driver, the participant drove the car as quickly and smoothly as possible through a lap on a winding road. When functioning as the passenger, the participant was tasked to count the number of oncoming cars. Two virtual worlds were used. The high-realism world had a blue sky, a hilly road surface and surround, a green background with red farmhouses, oncoming cars, and guard posts. The low-realism world showed only a black sky and background, the road surfaces were flat, and there were no peripheral objects such as farmhouses and oncoming cars. These worlds were viewed on a monitor using shutter glasses to provide a stereoscopic viewing. Presence was assessed using the paired comparison method, where participants indicated in which of the worlds they felt more physically located and rated the difference between the two virtual worlds. In each of two experiments, scene realism had a relationship with presence and an interaction with the role that the participants played. Participants reported significantly more presence for the high-scene detail/driver condition than for the low-scene detail/passenger condition. (One of the experiments also examined the effect of end-to-end

latency, the delay between a user's action and that action being reflected in a display, and researchers found that an additional 1.5-second delay in visual feedback significantly reduced the sense of presence.)

Additional experiments conducted by other researchers have examined the differences of such combinations of lighting quality and texture resolution (see Dinh et al. (1999)), a realistic or abstract terrain (see Johnson and Wightman (1995)), and transporting a user through virtual worlds by donning simulated HMDs or going through portals (see Slater et al. (1994)). These are all too dissimilar to allow general conclusions to be reached. Moreover, the importance of scene realism is most likely task related, and empirical results will be particularly difficult to generalize.

Self-representation

As already seen in Slater and Usoh's studies that looked at navigation methods, a user's self-representation is associated with his sense of presence. This effect has been examined in four experiments. One of these contrasted the use of a simple, full-body representation with that of a virtual pointer (see Singer et al. (1998)). The full-body avatar was linked to a participant's movements using trackers on the head, shoulder, feet, right arm, and right hand. The pointer was mapped to the right hand. Wearing an HMD, participants searched for briefcases placed around a typically furnished virtual office. They navigated through the area using a custom hand-held wand. As each briefcase was found, the participant pressed a button on the wand, and the brief-case disappeared. Surprisingly, self-representation was not related to Witmer-Singer PQ scores, or, indeed, to performance measures related to the number of collisions, time taken, and number of targets acquired. The hypothesis that was suggested to account for the absence of such relationships was that the HMD effectively cut off participants' view of their lower body.

A second experiment was conducted to investigate this further. Participants performed a slightly different task in the second experiment, termed a replication by the researchers (see Allen and Singer (2001)). This time, they had to complete a guided navigation task and then search for floor locations in order and drop markers on them. Instead of a virtual pointer, in one condition, the participant's hand was mapped to a virtual hand. Several real-world conditions were added using a mockup HMD constructed from plastic welders goggles with cardboard cutouts and masks that appropriately reduced resolution and luminance to match the visual characteristics of the HMD. These additional conditions provided an expanded horizontal visual field, an expanded lower visual field, and a normal visual field. Again, using the Witmer-Singer PQ, the results for the virtual-world conditions were similar to those of the first experiment, with the form of self-representation showing no relationship with overall presence scores. There was a significant difference in the second experiment for the PQ Natural subscale, where participants rated the

disembodied, virtual-hand representation as more natural, perhaps because they had to look down at an unnaturally sharp angle to see and use their full virtual representation. In comparison with the real-world condition that matched the HMD, participants presence scores (on all subscales except Natural) were significantly higher in the virtual world. The PQ subscales indicated that participants found that controlling the virtual world was easier and that the virtual world was less interfering, which made it easier to examine objects. The researchers question whether this preference for the virtual world could be the result of anchoring biases on the part of the participants (e.g., being unaccustomed to viewing the real environment through a masking helmet). There were also significant differences among the real-world conditions for all but the Involved/Control subscale. Additional analyses found a significant, positive correlation between presence and FOV in these conditions.

The two other experiments in this area are not comparable. However, one reported by Slater and Usoh (1993) also compared self-representation using an avatar and an arrow cursor. These researchers did find that participants who had an avatar reported more presence. A fourth experiment compared the effects of generic and realistic portrayal of participants' hands and found no significant difference in reported presence (see Lok et al. (2003a)).

Stereoscopy

The effect of stereoscopic displays on presence was another factor examined in the experiments reported by Freeman et al. (2000) and Ijsselsteijn et al. (2001a). In a series of counterbalanced trials, participants viewed the video stimuli stereoscopically and monoscopically (without polarized glasses). Presence was rated using a visual analog scale. Both experiments found that stereoscopy was related to presence, with participants reporting significantly more presence for the stereoscopic presentation.

The findings of several additional experiments that had a consistent finding are discussed in the next section (see Section 2.1.2).

Update rate

There is general agreement that the rate at which a graphical scene is updated influences presence. A fast update rate that presents smooth movements will not cause perceptual conflicts that may occur from a slower rate. Barfield and his colleagues performed two experiments designed to determine what update rate was "good enough." The first experiment examined update rates of 25, 20, 15, 10, and 5 Hz. The second compared update rates of 20, 15, and 10 Hz and also manipulated the type of device used for navigating through a virtual world (3 DOF joystick or 3 DOF SpaceBall). Both experiments had participants search through a reconstruction of

Stonehenge looking for a rune inscribed on one of the menhirs. The virtual world was presented on a 6×8 foot rear-projection screen. Barfield and Hendrix (1995) found that participants reported significantly less presence for the 5- and 10-Hz update rates than for the 20- and 25-Hz update rates, when considering overall presence rating and other questions directly related to presence. There were no significant differences for two additional items related to participants' awareness of the real world or simulation speed. Update rate also had a significant association with the perceived fidelity of interaction. In the second experiment (see Barfield et al. (1998)), a slightly longer version of the presence questionnaire was used. Again, update rate was found to have an effect on presence. Depending on the question, a significant difference was found between 20 Hz and lower rates or between 15 Hz and 10 Hz rates. Again, additional experiments that investigated this factor are discussed in the next section (see Section 2.1.2).

Visual displays

A relatively large number of experiments have looked at how different types of display devices may influence the sense of presence. The displays examined range from 6-sided Caves to the screen of a Personal Digital Assistant (PDA), but most experiments used HMDs and desktop monitors. Slater and his colleagues have conducted a series of such experiments as part of the European COllaborative Virtual ENvironments (COVEN) project. The virtual world used in these experiments was a model of the actual laboratory where the study took place. It included a room that had sheets of papers displayed around the walls. Each sheet had several words in a column, and each word was preceded by a number. The words across all sheets with a common number combined to form a saying. Participants worked in groups of three to solve these word puzzles. One participant viewed the virtual world through an HMD, and the other two participants used desktop monitors. The first of these experiments was intended as an exploratory study to generate hypotheses about how participants would behave in such a collaborative task, and each group of participants performed the task in the virtual world first and then in the real world (see Slater et al. (2000b)). The VE systems used by the participants were connected over a local area network (LAN). In a second experiment conducted to assess the feasibility of additional research, participants collaborated over a wide area network (WAN). No data from that study have been published. Two more experiments were conducted using the WAN (see Tromp et al. (1998 (2)) and Steed et al. (1999)), and there were some differences in response times as compared with the first study. Also, some of the nonnative, English-speaking overseas participants had language difficulties that probably affected the collaboration. The SUS Questionnaires used in these experiments varied in length. Regardless, in all experiments, participants who used the HMD reported significantly more presence than those who used monitors. These experiments also collected data

on participants' feeling of co-presence and collaboration, and the relevant findings are discussed later.

Although relatively few multiuser experiments have been reported in the literature, another replication that looked at types of visual display also used groups of participants. This time, a series of three experiments compared the effects of Cave displays and desktop monitors. Cave participants wore shutter glasses to achieve a stereoscopic display. The virtual world used in these experiments presented eight cubes with one of six colors on each side. The challenge was to assemble the cubes so that each side of the resulting structure displayed a single color. In the experiments reported by Axelsson et al. (2001) and Wideström et al. (2000), one participant was in a 5-sided Cave, and his partner viewed the virtual world on a monitor. In a third experiment (see Schroeder et al. (2001)), some pairs used 5- and 4-sided Caves, and others used a 5-sided Cave and monitor. Other differences among the experiments are unknown. The experiments used the same two-item presence questionnaire. Alexsson and Schroeder also reported on an additional one-item rating of the sense of the virtual world as a place visited. In all cases, Cave participants gave significantly higher presence scores and rating of the virtual world as a place to visit. Schroeder also reports that whether the Cave had five or four sides made no difference. The place-to-visit rating also indicated that immersed participants whose partner was also immersed experienced more presence than those whose partners used the desktop monitor. A later extension to this work added conditions in which some participants collaborated using either a 5-sided Cave and an HMD or using two desktop monitor displays (see Heldal (2005)). The findings in this case support Schroeder's conclusions. Participants who used displays of similar immersiveness (Cave-to-Cave, Cave-to-HMD, monitor-to-monitor) reported levels of presence similar to those of their partners, and, for desktop monitor participants, the level of presence was significantly lower when their partner used a Cave than when their partner used another desktop monitor. Looking across conditions, participants who used Caves or the HMD still reported more presence than those who used desktop monitors. Not only was immersiveness associated with an increase in the sense of presence, but the researchers also report that participants' performance in the immersive display conditions was close to that in a real-environment setting. These experiments also looked at co-presence and relationships between presence and collaboration, discussed in a later section.

Mania and her colleagues conducted two experiments comparing the effects of HMDs and desktop monitors when participants worked individually. The main goal of the first experiment (see Mania (2001b)) was to determine whether different types of lighting effects were related to the sense of presence, and the graphics were generated from photometry data acquired in a real-world space. The virtual world was a recreation of a 4×4 meter room that contained typical office furnishings. The participants' task was simply to observe the virtual world. This

was viewed either stereospically or monoscopically using an HMD or desktop monitor. For the sense of presence, the consequences of using head-tracking or a mouse for changing the participant's view was also considered. The type of visual display and interaction device was not related to any significant differences in presence scores (although lighting quality had a significant negative correlation with presence). A second experiment used the same range of display devices and same virtual world to investigate the use of human memory states for assessing the simulation fidelity of a virtual world (see Mania et al. (2003)). It also found that the type of display device used was unrelated to the sense of presence. While these replications gave consistent results, their finding differs from those of Slater, Steed, and Tromp. It is unknown whether this difference was a result of the different experimental tasks, the questionnaires used, or some other factor(s). More than 10 additional experiments were inconsistent in their findings for the effect of HMDs and monitors on the sense of presence. When presence ratings did differ, however, the finding was that participants using HMDs experienced more presence.

2.1.2 Consistent Results Across Different Experiments

Consistent results across several experiments with differing characteristics can be an indication of the importance of a particular technical characteristic and the generalizability of its findings across different environments. This cannot be stated with any degree of certainty. There is always the possibility that one additional experiment will bring previous results into question. For the space available here, there was no attempt to address the causes of conflicting results, to suggest that they mean a particular technical characteristic has no direct relationship with presence, or to argue whether they result from legitimate differences in experimental protocols. Instead, the discussion is restricted to those cases where experimental findings agree. Table 3 lists these experiments. The experiments already discussed as replications are indicated by *italics*.

Field of view (FOV)

Eight experiments have examined the effect of FOV using HMDs, large projection screens, or desktop monitors. All these experiments found that participants reported significantly higher levels of presence for larger FOVs. A closer look at this research provides some interesting details.

FOV is an example of a technical characteristic that poses different concerns for different types of visual display devices. It is particularly challenging for HMDs, where the size of the optics and tradeoffs with resolution can impose severe limitations. Prothero and Hoffman (1995b), Snow (1996 (1)), and Allen and Singer (2001) used different HMDs that provided

Table 3. Technical Characteristics With Consistent Findings for Presence

Factor	Conditions	Significant Relationship (Condition(s) Yielding Most Presence)	Presence Measure	Experiment Reference
FOV	180º, 140º, 100º, 60º	180º > 100º, 100º > 60º	9-item questionnaire	(Lin 2002)
	180º, 150º, 120º	180º > 120º	8-item PQ	(Shim 2003)
	40°V × 105°H	Unrestricted (females)	5-item questionnaire	(Prothero 1995b)
	120º, 60º	120º	IPQ	(Seay 2001)
	50º, 28º	50º (moving stimulus)	Rating scale	(Ijsselsteijn 2001a)
	48º × 36º, 36º × 27º, 24º × 18º	48º × 36º	Magnitude estimation ratio-scale	(Snow 1996 (1))
GFOV	90º, 50º, 10º	90º, 50º	6-item questionnaire	(Hendrix 1996a (3))
Haptic cues — Force feedback	Delivered to fingertip, absent	Delivered to fingertip	PQ	(Sallnäs 2004 (6))
	Delivered to fingertip, absent	Delivered to fingertip	PQ	(Sallnäs 2000)
	Delivered to fingertip, absent	Delivered to fingertip	Presence questionnaire	(Petzold 2004)
	Environmental and collision preventing, environmental, absent	Environmental and collision preventing, environmental	3-item questionnaire	(Lee 2004)
Navigation	*Walking-in-place, 3-D mouse*	*Walking-in-place* [2]	*3-item SUS Questionnaire*	(Slater 1995a)
	Real walking, walking-in-place, push-button-fly	*Real walking*	*7-item SUS Questionnaire*	(Usoh 1999)
	Walking-in-place, hand controlled, gaze controlled	Walking-in-place	IPQ	(Schuemie 2005)
Stereoscopy	*Present, absent*	Present	Rating scale	(Freeman 2000)
	Present, absent	Present	Rating scale	(Ijsselsteijn 2001a)
	Present, absent	Present	4-item questionnaire	(Cho 2003)
	Present, absent	Present	4-item questionnaire	(Cho 2003)
	Present, absent	Present	5-item questionnaire	(Hendrix 1996a (2))
	Present, absent	Present	PQ	(Singer 1995)
	Present, absent	Present	Magnitude estimation ratio-scale	(Snow 1996 (2))
Texture mapping	Present, absent	Present	4-item questionnaire	(Cho 2003)
	Present, absent	Present	Magnitude estimation ratio-scale	(Snow 1996 (2))
Update rate	*20, 15, 10 Hz*	*20, 15 Hz*	*18-item questionnaire*	*(Barfield 1998)*
	25, 20, 15, 10, 5 Hz	*25, 20 Hz*	*13-item questionnaire*	*(Barfield 1995)*
	16, 12, 8 Hz	16 Hz	Magnitude estimation ratio-scale	(Snow 1996 (1))
Frame rate	30, 20, 15, 10 fps	30, 20 fps	UCL Questionnaire	(Meehan 2001 (3))

2 For participants who had a strong association with their virtual body.

monoscopic viewing with different resolutions. Using a Division, Ltd. dVisor HMD, Prothero and Hoffman compared the device's 40° × 105° FOV with a reduced FOV that was achieved using modified tanning goggles. Since the aperture on these goggles was very close to the eye, the eye mask had a different effect on direct (40°) and peripheral (60°) vision. The experimental task used Division, Ltd's SharkWorld, where participants had to catch sharks using a net. Prothero and Hoffman found an unexpected gender effect: only females' reports of presence differed significantly depending on FOV although, as expected, females reported more presence for the larger FOV. Also, considering all participants, the difference between viewing conditions was only significant when participants performed the task using the wider FOV first. This raised the question of whether participants' expectations for the virtual scenario were initially low, so that they were accepting of a smaller restricted FOV unless they had already experienced a larger one. Based on related work that looked at the effect of foreground and background occlusion (discussed previously), the researchers felt that a larger difference between the conditions in this experiment would have been found with a background occlusion, such as a mask on HMD screens.

Snow examined FOV using a Virtual Research Systems, Inc., VR4 HMD and examined the effects of display resolution and update rate in addition to FOV. His participants performed tasks such as distance estimation and target selection in a virtual world comprised of simple rooms and left- and right-turn corridors. With only 12 participants, although using a within-subjects design, he found a significant difference between reports of presence for 48º × 36º, 36º × 27º, and 24º × 18º FOVs.

Ijsselsteijn et al. (2001a) compared participants' sense of presence when viewing a curved 1.9 × 1.45 meter projection screen with a 50º horizontal FOV (HFOV) against that experienced when viewing a 20-inch screen with an effective 28º HFOV. The stimuli were the rally car sequence and still image taken from the ACTS MIRAGE *Eye to Eye* documentary. The scenes were generated stereoscopically and viewed using shutter glasses. They found a significant interaction between FOV and image type, with more presence reported for the larger FOV when viewing the rally sequence.

Hendrix and Barfield (1996a (1)) used a 6 × 8 foot rear-projection screen and examined three levels of geometric FOV (GFOV) while holding the image size constant. The participants' task was simply to familiarize themselves with a virtual room, with a different room used for each condition. Hendrix found that reports of presence were significantly lower for a 10º GFOV than either a 90º or 50º GFOV. Although participants experienced all three GFOV conditions, they seemed unaware of the experimental manipulation. They described the different virtual rooms

used in each condition as bigger and more spacious or smaller and more cluttered but did not mention that different viewing angles were used. Hendrix concluded that the different bandwidth of spatial information provided by changes in GFOV affected the sense of presence.

The next two experiments considered much larger FOVs. Shim and Kim (2003) compared 180º, 150º, and 120º HFOVs using a panoramic display comprised of three large-scale TV displays. Concerned with how various technical characteristics could be manipulated to get the most from a given hardware setup and limited computational resource, this work considered both FOV and the level of simulation detail. Participants viewed a virtual fish tank containing 30 fish that exhibited different levels of behaviors. Shim and Kim found a significant difference between presence reported for the 180º and 120º FOVs. Simulation level of detail also had a significant effect on presence, but the expected interaction between these experimental factors, such that a larger FOV would allow participants to recognize the difference in fish behaviors, was not found.

Another experiment used the Real Drive driving simulator that includes a full-size Saturn car on a motion platform. This simulator also used a panoramic display (three 230 × 175 centimeter projection screens), and participants viewed a stereoscopic presentation using CrystalEyes stereo glasses. As part of a series of experiments investigating simulator sickness, Lin et al. (2004) found that participants reported significantly more presence for an FOV of 180º than 100º and more presence for 100º than for 60º. The lack of a statistical difference between presence for 180º and 140º led these researchers to hypothesize an asymptote effect beyond 140º. Shim and Kim's results support this conclusion.

Haptic cues

Four experiments have used SensAble Technologies Inc. PHANTOMs to examine the influence that providing force feedback to a fingertip may have on task performance. The tasks performed were very different. In the earliest experiment (see Sallnäs et al. (2000)), pairs of participants collaborated in five different tasks. Four of these tasks involved building patterns with a collection of eight cubes, and the other task was to navigate through a pattern constructed of cubes. The standard PHANTOM device provides only a single-point interaction. To lift a cube, participants had to collaborate in pushing up on a cube from different sides, or a participant could press a cube against one of the walls and push upward. The cubes had simulated form, mass, damping, and surface friction. Force feedback was also provided for the walls and for each partner, with a slight vibration used to distinguish between touching a cube and touching or holding onto a partner. Despite the limited nature of the haptic cues, the participants who performed the experimental tasks with force feedback reported significantly more presence than those who

performed tasks with no such cues. Sallnäs (2004 (6)) found the same result in a later experiment where participants passed cubes of varying size between themselves.

The other two experiments that used the PHANTOM investigated the sense of presence for tele-operation tasks. For the problem of shared autonomy in controlling a mobile robot, Lee et al. (2004) investigated how force feedback could support visual feedback in aiding participants to direct the speed and rate of turn for a robot with on-board obstacle collision. They compared the rendering of environmental and collision prevention information, environmental information only, and no feedback. Participants were trained in a virtual world and then were tested in an equivalent real environment. The type of forces provided had a significant effect on the number of collisions (though not the time to complete a navigation task). Also, significantly more presence was reported for the force feedback conditions than for the no feedback condition, even though the methods employed only provided indirect information about the robot's environment. The researchers hypothesize that the indirect haptic cues improved presence because they acted as a local spatial cue for a participants' perception of the space.

Petzold et al. (2004) compared the use of force feedback with video feedback in a tele-presence system for micro assembly, where the actual assembly was performed by a Bosch SR6 Turboscara robot. In the force feedback condition, 6 DOF forces measured by a sensor were fed back to a PHANTOM. In both conditions, scenes from two cameras were displayed on the video monitor. One of these scenes was a bird's eye view of the assembly area, and the other provided a side view. The experimental task was to mount an hour-wheel onto the corresponding minute-wheel of a wristwatch clockwork. Here, again, providing force feedback significantly increased the reported sense of presence.

The differences among these experiments necessitate caution in assuming that their consistent results can be generalized to other applications. It is likely that the relationship between force feedback and presence is highly dependent on the purpose and form of that feedback. In many cases, researchers have reported difficulties with using force feedback devices that might adversely affect a user's sense of presence.

Additional experiments have investigated the use of passive haptics on presence. Here, real objects in the real world are registered with virtual objects to provide haptic cues (see Insko (2001 (2)), Lok (2003a), Hoffman (1996), and Meehan (2001 (2))). A few researchers have also looked at the use of fans and sun lamps to simulate environmental conditions such as breezes and heat from standing in sunlight (see Noel (2004) and Dinh (1999)). None of this work has involved replicated studies, and the results are mixed.

Navigation

Slater and Usoh's finding that walking-in-place allows a higher sense of presence than less-natural navigation approaches has been confirmed in an additional experiment. This more recent experiment was concerned with identifying a practical locomotion method for use with virtual worlds designed to treat phobias. Conducted by a different group of researchers (see Schuemie et al. (2005)), participants first had to navigate through a couch- and plant-filled room that was designed to test the controllability of various interaction techniques. Then, participants ascended in an elevator to another area of the virtual world. After leaving the elevator, they found themselves on the roof of a tall building in a city scene. The task in this new environment was to search for boxes that were placed around the area to bring them close to large vertical drops. As in the work reported by Slater and Usoh, these participants also used HMDs to view the virtual world. Again, those who navigated using walking-in-place reported significantly higher levels of presence than those who used a hand-controlled device or an approach based on head-tracking.

Stereoscopy

In addition to those experiments reported by Freeman and Ijsselsteijn, four additional experiments have compared the use of stereoscopic and monoscopic displays. The VE and participant tasks mentioned for Hendrix and Barfield (1996a (1)) in the discussion on audio cues were used for this purpose. Cho et al. (2003) had participants view 32 versions of an undersea virtual world. The work discussed by Singer et al. (1995) examined participants' performance in a series of part tasks. These tasks were chosen from a set collectively called the Virtual Environment Performance Assessment Battery (VEPAB) (see Singer et al. (1995)). Finally, Snow's examination of stereoscopy was similar to that of Singer in that he examined participant performance on discrete tasks, such as a series of movement, target selection, and distance estimation (see Snow (1996 (2))).

Collectively, this group of experiments used an HMD, a large rear-projection screen, a curved projection screen, a 20-inch monitor, and a 50-inch monitor. All but one of these displays were updated in response to participants' head movements. In two of the experiments, participants simply watched the display or navigated around a virtual room. The two other experiments required cognitive effort rather than physical interaction with elements of the virtual world. The presence measures were multi-item questionnaires, rating scales, and a magnitude estimation ratio-scale. In all cases, the provision of stereoscopic images resulted in a significant increase in the reports of presence.

Texture mapping

Only two experiments report on the potential relationship between of texture mapping and the sense of presence. It was one of the factors examined by Snow (1996 (2)) in his series of experiments. These experiments used the same virtual world (rooms connected by corridors with left and right turns), modified as appropriate for each particular investigation. All participants used an HMD and performed part-tasks such as moving through corridors or selecting targets. Snow found that participants reported significantly higher levels of presence when texture mapping was used.

Cho et al. (2003) looked beyond texture mapping to investigate how visual cues could be combined to promote presence. Their hypothesis was that "where" cues, such as stereoscopy and motion, would contribute more to presence than "what" cues, such as geometry and texture. They used a simple virtual world showing an underwater scene, which was viewed using a 50-inch screen. They found that texture mapping did have the expected significant effect on presence. In addition, they found that texture, geometry, user motion, object motion, and stereoscopy played different roles in user perception of realism and presence. Texture and geometry were more important for the perception of realism, whereas stereoscopy, object motion, and user motion were predominant for presence. The interactions caused by the "where" cues in combination with "what" cues also played important roles for presence.

Although Snow and Cho et al. found consistent results for the presence of texture mapping, data on the effects of different texture resolutions are mixed (see Dinh et al. (1999), Vinayagamoorthy et al. (2004), and Zimmons and Panter (2003)).

Update rate

Snow also looked at the effect of visual update rate on presence (see Snow (1996 (1))). Using an HMD with head-tracking, he found an increase in reported presence as the update rate increased. Participants reported significantly higher presence for scenes updated at a 16-Hz rate as compared with those updated at an 8-Hz rate. This finding is consistent with that of Barfield et al. (1995) discussed previously.

Instead of cycles per second, Meehan reports update rate in terms of frames per second (fps), comparing presence reported at 30, 20, 15, and 10 fps. Again, participants used an HMD with head-tracking. As in all Meehan's experiments, their task was to carry a book around a virtual pit and place it on a chair on the far side of the pit. A large-area optical tracking system was used to allow participants to walk naturally in the area represented by the virtual world. Using the Reported Behavioral Presence part of the UCL presence questionnaire, Meehan (2001 (3)) found

a significant difference between each of the two faster frame rates (30 and 20 fps) and the 15 fps frame rate. Frame rates below 15 fps were associated with anomalous behavior. It is important to note that frame rate did not show any effect on the Reported Presence part of this questionnaire. This experiment is still included in this group since additional measures based on observations of participants' behavior and changes in participants' heart rate, skin conductance, and skin temperature confirmed a difference among the experimental conditions.

2.1.3 Summary

In all but one case, a replicated experiment(s) had a consistent finding with the initial experiment. In most cases, the results were as expected. An increased sense of presence was associated with stereoscopic viewing, faster visual display update rates, walking-in-place to navigate through a virtual world, spatialized sound, an increased number of audio channels, image motion, increased scene detail, high presentation quality, presenting the virtual world as a background scene, and using a Cave instead of a desktop monitor. While the nature of the tasks to be performed in a virtual world has some influence on the importance of all these technical characteristics, the findings for stereoscopic viewing and update rates probably apply to most VE applications. So, it is encouraging that these findings were supported by additional experiments that used different interfaces, virtual worlds, and experimental tasks. For virtual worlds that represent large spaces, the results of two early experiments that studied walking-in-place have also been confirmed in a recent experiment conducted by a different group of researchers. However, an important point to remember is that many of these other experiments used different presence measures, and whether all these measures tap into a common presence construct is unknown.

Replicating experiments builds confidence in the reliability of the results. However, when a technical characteristic has only been examined with one set of interfaces, virtual world, and task, researchers cannot be certain that the findings will hold under different conditions. This is the case for using a Cave display. Caves are expensive visual display systems and beyond the reach of many research budgets. Perhaps that explains the lack of data comparing the effect of Caves and HMDs on presence with the effect of other visual display devices. Data are needed on the effect of Cave displays for a range of tasks, as are data that look at alternative types of visual displays. In particular, there is a need for empirically established guidelines on the types of applications best suited to each type of display. Without such information, trying to interpret the mixed findings of the nearly 20 experiments that compared the use of HMDs with projection screens or desktop monitors is impossible.

Another important point is that several of the examined technical characteristics can vary over a large range of values, and computational and interface device costs generally increase substantially at the extremes of the range. Consequently, it is important to determine the point at which further improvement is redundant. The characteristics of human perception often provide a theoretical upper bound; however, since behavior at these limits is often complex and not well understood, task considerations become even more important. In any event, the technology has not reached these limits in most cases.

The lack of consistent results across experiments is surprising in a few cases. The role of head-tracking in supporting a more natural interaction with a VE would seem likely to be related to the sense of presence for most types of tasks and be a strong enough relationship to show across different environments. Yet, one of the three experiments that investigated this effect using HMDs and one of two that used rear-projection screens failed to find a difference between head-tracking and no head-tracking conditions (see Bailey and Witmer (1994 (2)), Singer et al. (1995), Snow (1996 (2)), Bystrom and Barfield (1999), and Hendrix and Barfield (1996a (1)).

The lack of consistent results across experiments is also surprising for the use of passive haptics. The term *passive haptics* is used to describe cases where a virtual world is registered with real objects so that the user, for example, can grasp and move a physical object while seeing its virtual representation. (This is different from augmented reality, where virtual objects are superimposed on a real environment.) Five experiments had investigated the potential relationship between passive haptics and presence. Although these experiments differed in the types of real objects that were used and in the experimental task itself, this is another case of a factor that could be expected to have a large enough relationship with the sense of presence to show across a range of VEs. Yet, this was not the case. Three of the experiments found no effect of passive haptics on the sense of presence. Of the remaining two, one found that the use of passive haptics had an effect only on reports and observations of behavioral measures of presence.

There are two cases where the effect of a particular technical characteristic on presence has been examined in only a single experiment, but the large number of participants makes the results compelling. Biocca et al. (2001) examined cross-modal interactions and their effect on presence. Seventy-seven participants removed organs from a virtual cadaver in the Media Interface and Network Design (M.I.N.D.) Lab’s Virtual Hands-on Cadaver Environment and then performed the equivalent task in a different environment that provided a collection of simple symmetrical polygonal shapes occupying the same space and location as organs in a cadaver. The researchers found that reports of cross-modal visual-to-haptic illusions had a significant positive correlation with presence, whereas reports of cross-modal visual-to-aural illusions had no

relationship with presence. In the only other case where 50 or more participants performed the same task under the same conditions, Meehan et al. (2003) looked at the relationship between latency and presence. Using a task in the UCL's virtual pit world, viewed with an HMD, these researchers found no significant difference in reported presence between approximate 50-ms and 90-ms end-to-end latencies.

2.2 Task Characteristics That Affect Presence

Several task characteristics that may be related to presence have been examined. In the sense used here, a "task characteristic" does not relate to *what* activities are performed in a virtual world but, rather, the *manner* in which a participant is asked to complete a task. This includes, for example, task difficulty, providing different types of navigation information, and how users may be required to collaborate. As these examples indicate, task characteristics are usually not directly dependent on hardware and software limitations. Forty-seven experiments in this category have been reported in the literature. Table 4 identifies the task characteristics that have been examined. Only one task characteristic has been examined in a replicated experiment, although four sets of related experiments have consistent findings.

Table 4. Task Characteristics Examined for Presence

Avatar and agent role	Personal risk (virtual)
Audio cues	Practice with interface
Collaboration	Priming
Directions	Realism
Distance cues	Second user
Elapsed time to testing	Task difficulty
Familiarity with world	Task expertise
Interaction (level of)	Time spent in VE
Meaning	Training type
Mediation	Viewing alone/group
Multiple exposures	

2.2.1 Replications

Meehan (2001) conducted a series of three experiments in which participants performed the same task in a virtual world that contained a 20-foot pit. The first experiment investigated the hypothesis that multiple exposures to a virtual world would lead to a decline in the sense of presence. The primary goal of the second and third experiments was to look at the use of passive haptics and frame rate, respectively, but Meehan used the opportunity to collect additional data on repeated exposures. For the first experiment, participants performed the experimental task three times a day on four successive days. The task was to walk round the chasm on a narrow ledge to place a book on a chair on the far side. Participants used an HMD. Levels of presence did decline on the UCL Reported Presence subscale, but increased exposure did not show any association with the UCL Reported Behavioral Presence subscale scores. In the next two experiments, participants only performed the task twice, so those results are best compared against each other. One experiment found a significant negative correlation between exposures and reported presence, and the other experiment found a negative

correlation with the Reported Behavior Presence subscale but no relationship with the Reported Presence subscale. There also were inconsistent results on physiological measures based on changes in heart rate, skin conductance, and skin temperature and for an observed fear response.

2.2.2 Consistent Results Across Different Experiments

The effect of multiple exposures on presence has been investigated in two other experiments that did find consistent results. Consistent results across experiments have also been found for the role of avatars, the level of participant interaction in a task, and task difficulty (see Table 5).

Avatar and agent role

Four experiments have investigated the influence that avatars and agents may have on the sense of presence when they directly interact with a participant. Agents played the role of a fitness trainer who coached a participant exercising on a stationary bicycle (see Ijsselsteijn et al., 2004), an advertising agent who provided product descriptions (see Choi et al., 2001), and a predictor of motions to reduce simulator sickness in a motion-based driving simulator (see Lin et al., 2004). Snow (1996 (3)) used an avatar who accompanied a participant while he completed various tasks in a virtual world. In all cases, the presence of the avatar or agent significantly increased the amount of presence reported by participants, regardless of how compelling each experience was and whether the virtual world was viewed immersively. None of the agents or the avatar was required for task performance. At most, they provided information that a participant could choose to use in modifying his behavior.

The two experiments where the virtual character was a passive spectator found that the mere presence of an agent had no relationship with reports of presence. Schubert et al. (2000 (1)) represented an agent by footprints that appeared crossing a corridor after a door had opened. In the other experiment, Usoh et al. (1996) used agents in the form of cardboard cutouts. These agents stood by desks while a participant performed tasks in a virtual laboratory. Although these experiments had consistent results, the effect that more human-like representations would have had on the results is uncertain. Also, there are no data about whether an agent with behaviors, though still maintaining its independence of a user, might be associated with the user's sense of presence.

Table 5. Task Characteristics With Consistent Findings for Presence

Factor		Description	Significant Relationship (Condition(s) Yielding Most Presence)	Presence Measure	Experiment Reference
Avatar and Agent role	Passive	Shoes moving across corridor, no agent	–	IPQ	(Schubert 2000 (1))
		Standing by desks, no agent	–	3-item SUS Questionnaire	(Usoh 1996)
	Interacting	Advertising agent, no agent	Advertising agent	10-item questionnaire	(Choi 2001)
		Virtual fitness coach, no agent	Positive	ITC-SOPI Spatial Presence, Negative Effects	(Ijsselsteijn 2004)
		Non-earth-fixed with turn cues, earth-fixed without turn cues, no agent	Non-earth-fixed, earth-fixed	9-item questionnaire	(Lin 2004)
		Accompanying participant, no avatar	Accompanying participant	Magnitude estimation ratio-scale	(Snow 1996 (3))
Interaction (level of)		Controlling bicycle direction and velocity, guided	Controlling bicycle	ITC-SOPI	(Ijsselsteijn 2004)
		Actor, observer	Actor	SVUP	(Larsson 2001)
		Pilot, observer	Pilot	5-item questionnaire	(Nicovich 2005)
		Driver, passenger	Driver	IPQ	(Seay 2001)
		Driver, passenger	Driver	Paired comparison	(Welch 1996 (1))
Multiple exposures		After last mission rehearsal, after first mission rehearsal	After last mission rehearsal	PQ	(Commarford 2001)
		After first mission rehearsal, after final training	After final training	PQ	(Commarford 2001)
		After final training, after movement training	After final training	PQ	(Commarford 2001)
		First, second	Second	PQ	(Riley 1999)
Task difficulty		Large number of mines, small number	Large number	PQ	(Riley 2001)
		Simple count, count and remember location	Simple count (females only)	SUS Questionnaire	(Slater 1998)

Interaction

Two of the five experiments that investigated the relationship between the level of user interaction and the sense of presence employed driving tasks where participants took the role of either a vehicle driver or a passenger. Using a panoramic display consisting of three 3 × 6 foot screens, with the user seated in front of the center screen, Seay et al. (2001) had participants take a 10-minute drive in a virtual car. Using a within-subjects design, participants controlled the car using a joystick and experienced guided navigation. In an earlier experiment along the same lines, Welch et al. (1996 (1)), had participants drive a car as fast and smoothly as possible along a winding road or, when the passenger, count the number of oncoming cars. These participants viewed the virtual world stereoscopically on a monitor using shutter glasses and were provided a steering wheel, foot-operated accelerator, and brake pedal to control the vehicle. In both cases, participants reported significantly more presence when they had the opportunity to control the virtual car.

Nicovich et al. (2005) also used vehicle control in his experiment, but this time the vehicle was a virtual plane. Participants in the high-interaction condition flew a takeoff and landing using Microsoft Flight Simulator 98. Other participants viewed a recorded video of the same game scenario. In addition to finding a significant advantage of interactivity for presence, Nicovich et al. found an interaction with gender, such that males reported significantly less presence than females in the noninteractive condition and significantly more presence than females in the interactive condition.

Larsson et al. (2001) compared participants' presence ratings after a different type of virtual scenario. Participants visited a recreation of Orgryte Nya Kyrka church in Gothenburg, Sweden. A female agent performed "Swanee River" while moving along a predetermined path through the church. Participants in the interaction condition counted the number of windows in the church and searched for four balls. When a participant approached a ball, a sentence appeared in the color of the next ball to be found. These participants were also asked to remember the sentences, though their memory was not tested later. These participants viewed the virtual world using a stereoscopic HMD. Participants in the noninteraction condition simply visited the church, and their visual display device was a screen. Again, participants in the interaction condition reported significantly more presence, although it is uncertain how much this result was influenced by the different type of visual display device used by each experimental group.

Finally, the experiment by Ijsselsteijn et al. (2004) that studied the effect of providing a fitness trainer in a home exercise application also considered the effect of different levels of

immersiveness. The two experimental conditions allowed different levels of user interaction and provided different representations of the virtual world. Some participants could control the direction and speed of their travel through a virtual landscape using the bicycle handlebars and pedals. These participants saw the landscape from the viewpoint of someone who was riding a bicycle. The application controlled the progress of participants in the noninteractive group. This latter group of participants saw an abstract picture of a racetrack in bird's eye view, with a dot indicating the position of the bicycle. All participants saw the virtual world on a wall-mounted screen. Not surprisingly, those in the more immersive condition reported more sense of presence. It is unknown how much this result was because of user interaction, how much was because of the different visual representations, or how much was because of some interaction of the two.

Multiple exposures

The results from two additional experiments that investigated the influence that repeated exposure to a virtual world might have on users' sense of presence had mutually consistent results that differed from those reported by Meehan. Commarford et al. (2001) had a different hypothesis. These researchers felt that repeated exposures would provide increasing familiarity and capabilities that would result in higher levels of presence. Their VE system was designed to investigate team coordination in distributed mission rehearsal. A series of virtual worlds were used, all based on a 10-room building with rooms laid out along a corridor with 1 turn. The system included stereo sound, voice communications, and sound effects such as collision noises, doors opening, grenade explosions, and gunfire. The visual display devices were HMDs, and participants navigated through the virtual worlds by walking-in-place. Participants were trained to perform a building search while being opposed by hostile computer-generated forces. They were trained to standard criteria on all tasks and activities and then performed eight missions in teams. Witmer-Singer PQ data were collected so that levels of presence could be contrasted after movement training and final training, after final training and the first mission rehearsal, and after the first and last mission rehearsals. In each case, presence was significantly higher after the later of the two activities.

In an investigation into the benefits of different types of navigational aids and display devices (HMD, projection screen, and monitor), Riley and Kaber (1999) asked participants to navigate a simulated telerobotic vehicle through an office environment consisting of nine rooms. They collected presence data after each of two trials and discovered a significant positive correlation between reported presence and exposure. These findings are consistent with those of Commarford et al., even when restricting the comparison to results collected after Commarford's participants had completed movement and final training.

Task difficulty

Task difficulty is another task characteristic for which a consistent relationship with presence has been found, although only two experiments have looked at this. One was an experiment performed by Riley (2001). This experiment was designed to investigate the use of measures of attention and situation awareness as objective measures of telepresence. Accordingly, Riley investigated the relationship among scores for a modified Cooper-Harper perceived workload scale, Situation Awareness Global Assessment Technique (SAGAT) queries for average situation awareness, hit-to-signal ratios for attention to monitoring tasks, and Witmer-Singer PQ scores. A primary and secondary task paradigm was used. The primary task was to use voice commands to operate the simulated robot to locate, uncover, identify, and neutralize land mines. The discovery of a mine was signaled by a ringing bell sound, and additional auditory cues marked collisions with objects. The secondary tasks were to monitor "real" environment displays on another monitor for visual signals indicating a critical event associated with the rover and controls in the teleoperation task. This was one of the longest experimental tasks among all the work discussed here, with 30 to 50 minutes allowed for each of two trials. Task difficulty was varied by manipulating the mine density. Participants' presence scores reflected the different levels of task difficulty: scores were significantly higher for a large numbers of mines (since these were easier to locate) than for a small number of mines. Riley speculated that participants became more frustrated with the difficulty of locating mines as the area between the mines increased, and this may have resulted in a detachment that reduced presence. Task difficulty had no significant relationship with situation awareness, attention, or workload. The explanation for the lack of effect on situation awareness may be that the information requirements of the task remained unchanged. Similarly, the change in task difficulty may have been insufficient to affect participants' abilities to perform the secondary task or influence the perceived workload. With respect to relationships among the various measures, the presence ratings had no significant relationship with average situation awareness or the ratio of attention scores across virtual and real environments. There was a significant negative correlation between presence and the perceived workload and between presence and the hit-to-signal ratio in the virtual world. Riley also found a significant negative correlation between presence and workload (measured using the National Aeronautics and Space Administration (NASA) Task Load Index (TLX)) in the earlier study where participants navigated a simulated telerobotic vehicle through an office environment (see Riley and Kaber (1999)).

Another experiment that looked at the effect of task difficulty on presence was reported by Slater et al. (1998). The main purpose of this research was to assess the influence of a user's body movement on the sense of presence in a VE. The hypothesis being tested was that the environment relative to which major body movements were made had a higher probability of being

the dominant environment. The investigation into the possible relationship between task difficulty and presence was a secondary objective. The experimental task, designed to manipulate both large body movements and task difficulty, was to move through a virtual field while counting the number of diseased trees. Healthy trees had green leaves, and diseased trees had one to four leaves with leaves with brown undersides. There were 150 trees, each with 16 leaves. The height of the trees was distributed as 1.7 ± 0.1 meters or 2.35 ± 1.9 meters, so that in one condition some participants had to bend more to see the underside of some leaves, whereas leaves in the other condition were all above normal standing eye level. In addition, in the highly variable height condition, some leaves were folded inward so that their status could only be determined from looking upward when beneath the tree. Task difficulty was manipulated by asking one group of participants to remember the location of diseased trees, in addition to counting them. The participants in the "remember group" had to draw these locations on a map after they left the virtual world. All participants used a stereoscopic HMD. Analysis of the data revealed that participants who experienced increased bending and standing reported significantly higher levels of presence. The same result was found for increased horizontal head movements. Task difficulty by itself was not related to any significant difference in presence scores, although an interaction with gender was found. Females in the more complex task ("counting and remembering") reported significantly lower presence than those in the simpler ("counting only") task.

2.2.3. Summary

The only task characteristic examined in a replicated study is multiple exposures, and Meehan did not find consistent results. However, two unrelated experiments, which used the same presence measures, did find that multiple exposures to a virtual world were related to an increase in participants' reported sense of presence. Reconciling these differences is difficult, and further research is needed. This research should also look at the effect of multiple exposures in different virtual worlds. What is the effect on a user who experiences a VE application that uses a different interface from the one with which he is familiar? Or the same interface he knows but a different virtual world and/or task? Most practical applications are intended for repeated use, so these may be important questions.

Several experiments found the expected result that participants who interacted with an avatar or agent reported higher levels of presence, but the mere presence of an agent was not associated with any difference in presence. The five experiments that manipulated the level of participant interactivity with a virtual world also found the expected result that the level of presence increased for more interactive tasks. In this last case, every experiment used a different presence measure, which could indicate that this task characteristic has a particularly strong effect.

This would be a reasonable assumption, but an important point to remember is that the active and passive roles used in these experiments were very different. A VE system intended for practical use may not provide such latitude, and the effect of smaller differences on interactivity is not known.

The final task characteristic examined was task difficulty. Two experiments found that increased task difficulty was associated with a decrease in reported presence. Out of the experimental laboratory, this effect may be more dependent on individuals' reactions to demanding tasks. In any event, these two experiments must be treated as a preliminary look at the potential role of task difficulty. More extensive research that carefully manipulates different types of work-related cognitive demands is needed.

3. Findings for Co-Presence and Social Presence

Research on co-presence and social presence in computer-generated virtual worlds began recently (if one excludes teleconferencing systems and the like), with most of the work having been performed in the last 5 years. Of the full set of 174 experiments looking at presence, only 33 considered either co-presence or social presence. Nearly half of this research is the work of only two groups: researchers at the University of California at Santa Barbara and another group at UCL (United Kingdom).

The treatment of co-presence and social presence is combined because some researchers use the terms synonymously. In the following discussion, researchers' terms are used for identifying their presence measurement instruments, but the tables include an additional column to denote whether they are treated as being relevant to co-presence or social presence. To recap, rephrasing the informal definitions given at the start of this document, co-presence occurs when people can sense others and are aware that others are aware of them. Social presence, on the other hand, requires an additional awareness of another person's role in an interaction.

3.1. Technical Characteristics for Co-Presence and Social Presence

Table 6 identifies the full set of technical characteristics that have been empirically examined. As the table indicates, most of the work has focused on the effect that agent characteristics may have on social presence and co-presence.

As before, the discussion starts by looking at what can be learned from replicated experiments. This time, broadening the scope to include those cases where diverse experiments have produced consistent results does not add any new technical characteristics. It only provides additional data to support replications in two areas.

Table 6. Technical Characteristics Examined for Co-Presence and Social Presence

Avatars and agents		
Behavioral realism	Co-presence	Social presence
Character realism	Co-presence	Social presence
Contact		Social presence
Agent gender		Social presence
Agent identity		Social presence
Perceived control	Co-presence	Social presence
Responsiveness		Social presence
Voice personality		Social presence
Haptic force feedback	Co-presence	Social presence
Presence manipulation	Co-presence	Social presence
Viewer type		Social presence
Visual display	Co-presence	

3.1.1. Replications

Table 7 identifies the sets of experiments that can be treated as replications. Four of the six sets concerned the use of avatars and/or agents. The other two examined different types of visual displays.

Behavioral realism

Of all the factors discussed in this section, the behavioral realism of agents has been studied the most. There is growing interest in human-agent interaction among many disciplines, and many researchers are finding that people respond to even quite basic agents as though they were human—assigning them intelligence and motivations that do not exist. In some respects, this may be advantageous since current abilities to model a wide range of realistic behaviors are limited. Gaze behaviors, such as moving an avatar's head to face the person talking, are relatively simple to implement, so it is not surprising that a large part of the study into agent behavioral realism has focused on this topic. There are two pairs of replications to examine.

In an initial experiment, Bailenson et al. (2001a) were investigating the equilibrium theory of proxemics, which specifies an inverse relationship between mutual gaze and interpersonal distance. Under the guise of studying memory, participants were asked to approach an agent in a virtual room and read the label on the back and front of its shirt. Participants used an HMD to view the virtual world and walked freely in the area represented by the virtual room. Five levels of behavioral realism were modeled for the agent: mutual gaze with eye dilation when a participant stepped within 0.75 meters of the agent, mutual gaze with no eye dilation, eyes open and blinking, eyes open, and eyes closed. As expected, participants reported significantly higher levels of social presence for mutual gaze conditions. Also, female participants responded more noticeably than males to the different gaze behaviors. This gender distinction was also evident in proxemic behavior, with female participants leaving a significantly larger interpersonal space around an agent that exhibited mutual gaze.

Table 7. Technical Characteristics Examined in Replicated Experiments for Co-Presence and Social Presence

Factor		Description	Significant Relationship (Condition(s) Yielding Most Presence))	Presence Measure	Type	Experiment Reference
Avatars and agents	Behavioral realism	Mutual gaze, eyes closed	Mutual gaze	5-item questionnaire	S	(Bailenson 2003 (1))
		Mutual gaze, eyes closed	Mutual gaze[3]	5-item questionnaire	S	(Bailenson 2003 (2))
		Gaze (5 levels realism)	Mutual gaze[4]	5-item questionnaire	S	(Bailenson 2001a)
		Inferred gaze, random gaze	Inferred gaze[5]	5-item questionnaire	S	(Garau 2003a)
		Inferred gaze, random gaze	Inferred gaze plus interact	2-item questionnaire	C	(Garau 2003b)
		Gaze (video, inferred, random, audio)	Video>audio>inferred>random	2-item quality of comm.	C	(Garau 2001)
	Identity	Tutor, stranger	–	5-item questionnaire	S	(Bailenson 2004b (1))
		Tutor, stranger	–	5-item questionnaire	S	(Bailenson 2004b (2))
	Voice personality	Extrovert, introvert	Extrovert[6]	4-item questionnaire	S	(Lee 2003 (1))
		Extrovert, introvert	Extrovert[7,8]	4-item questionnaire	S	(Lee 2003 (2))
Visual display		5-sided Cave, monitor	–	2-item questionnaire	C	(Axelsson 2001)
		5-sided Cave, monitor	–	1-item place-to-visit rating	C	(Axelsson 2001)
		5-sided Cave, monitor	–	2-item questionnaire	C	(Wideström 2000)
		5-sided Cave, 4-sided Cave, monitor	5-sided Cave	1-item place-to-visit rating	C	(Schroeder 2001)
		5-sided Cave, 4-sided Cave, HMD, monitor	5- and 4-sided Cave, HMD	2-item questionnaire	C	(Heldal 2005)
		HMD, monitor	–	Questionnaire	C	(Slater 2000b)
		HMD, monitor	–	4-item questionnaire	C	(Slater 1999)
		HMD, monitor	–	8-item questionnaire	C	(Steed 1999)

Key: *In the "Type" column, "S" stands for social presence and "C" stands for co-presence.*

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3 Also an interaction with participant gender, with significantly more presence reported by male participants.

4 Also an interaction with gender, such that females reported significantly more social presence for mutual gaze than males.

5 Also an interaction effect on each of social presence and co-presence, with the higher realism avatar used with inferred gaze yielding significantly more presence.

6 Also an interaction with participant personality, such that extroverts reported significantly more social presence for the extrovert computer voice and introvert participants reported significantly more presence for the introvert computer voice.

7 Also an interaction with participant personality, such that extroverts reported significantly more social presence for the extrovert computer voice and introvert participants reported significantly more presence for the introvert computer voice.

8 Also an interaction with item description content, such that the extrovert voice narrating extrovert text was associated with significantly greater presence than when reading introvert text and vice versa.

To examine gender effects more closely, the next experiment introduced agent gender as an additional factor (see Bailenson et al. (2003 (1))). The same results were found for gaze behavior. With respect to interpersonal distance, agent gender had a significant effect, with participants leaving significantly more space around female agents. When told that an agent was human controlled, participants left a larger space around an agent that exhibited mutual gaze. Also, female participants left more space around an agent perceived as human controlled than an avatar they were told was computer controlled—a response not shown by male participants. (These analyses were not reported for social presence ratings.) The researchers also collected data on agent likeability and memory of labels as cognitive markers of social presence. Agent gender had a significant relationship with the former, with male agents rated as more likeable. The scores from the memory test showed an effect only for agency, such that participants had significantly better recall for labels on avatars.

In a third experiment, researchers examined another aspect of proxemic behavior. This time, after a participant completed the label-reading task and one set of social presence ratings, the agent approached the participant. After experimenters observed a participant's response, the participant was asked to complete a second set of ratings. As in the previous experiments, participants reported significantly more social presence for agents that exhibited mutual gaze. This time, however, additional analyses were reported. The effect of agency was examined, and, as expected, social presence scores were higher for avatars than for computer-controlled agents. Similarly, significantly more social presence was reported for male agents than for female agents. The data did differ from those data collected previously in the interaction between gaze behavior and participant gender. This time, male participants (instead of female participants) were more sensitive to the experimental manipulation. The researchers suggested that this may have been the result of the more detailed models used for agents in this later work. The ratings for likeability showed no significant association with social presence scores. An item worth noting is that participants completed social presence questionnaires while in the virtual world in all the experiments reported by Bailenson et al.

Researchers at UCL examined a different type of gaze behavior (specifically, an eye model that distinguished between speaking and listening modes) but, again, adjusted the direction of an avatar's gaze based on the participant's head movements. Termed *inferred gaze*, the proportion of time that an avatar gazed directly at his partner depended on whether the participant was speaking or listening. (These durations were based on data from research on face-to-face dyadic conversations.) Inferred gaze was compared with a random gaze. In both experiments, participants worked in pairs on the same negotiation task. One participant played the role of a town mayor, and the other played the role of a baker whose families had a conflict. The task was

to reach a mutually acceptable solution within 10 minutes. The experiments used the same questionnaire to assess co-presence, although one also asked participants to report on their sense of social presence. One of the major differences between the experiments was that one (see Garau et al. (2001)) examined additional types of gaze behavior, including a direct video link between participants and an audio-only condition, while the other (see Garau et al. (2003)) also examined the effect of different levels of realism in depicting avatars. In addition, the later experiment explored the effect of using either a Cave or a monitor to view the virtual world, while the earlier one only used video monitors. (The researchers found no significant differences in co-presence and social presence scores based on the type of visual display that was used.)

Behavioral realism had a relationship with co-presence in both cases, and the findings were consistent, taking into account the disparity in gaze behaviors examined. Avatars that exhibited inferred gaze led to reports of significantly higher levels of co-presence. As would be expected, the video link, when provided, produced the highest levels of co-presence. Given the largely verbal nature of the task, it is perhaps not surprising that participants in the audio link condition reported the next highest level of co-presence. Character realism interacted with behavioral realism in an important way. Participants seemed to find a conflict between a realistic gaze and unrealistic body characterization, reporting significantly more co-presence for the more unrealistic gaze combined with unrealistic representation than for a mismatch between realism for gaze and representation.

Identity

Additional work reported by Bailenson et al. (2004b) considered the potential relationship between avatar (or agent) identity and social presence. Using the same basic task of approaching an avatar to read labels, identity was manipulated by telling the participants that the avatar either represented a stranger or embodied a computer tutoring program with which they had just worked. Avatar identity had no relationship with ratings of social presence, although participants left a significantly larger interpersonal space around the perceived stranger on the first (of two) trials. The experiment was repeated with additional trials to investigate this potential trial order effect. The replication found the same lack of effect of avatar identity on self-reports of social presence. This time, however, there was a significant difference in minimum interpersonal distance for all trials. In addition, there was a linear trend for participants to leave an increasingly larger distance around the agent on subsequent walks. The researchers had expected participants to leave more space around the perceived stranger and not around the embodiment of the computer program. They suggest that participants may have been treating the tutor as someone who provides knowledge (and of higher status than themselves). Bailenson et al. recommend further

research into this behavior to determine why participants' approaches differed on the profile sides of the avatar and to investigate the trend to leave a larger space across trials. A dissimilar experiment that used a different type of avatar identity is discussed in the next section (see Section 3.1.2).

Voice personality

Another pair of experiments has investigated how agent voices that portray different personalities may influence users' sense of social presence. Using two different Web scenarios, both providing information about products, Lee and Naas (2003 (1) (2)) found consistent results: matching a synthesized voice to an extrovert or introvert participant personality significantly increased the sense of social presence. Both experiments also revealed that extrovert participants were more sensitive to the effect, suggesting that an extrovert synthesized voice should be used if a user's personality is unknown. The second experiment also found that matching topic content to the personality of the synthesized voice significantly increased social presence. Knowing how these findings generalize for other applications would be useful. If an application already provides synthesized voices, this may be an easy way to manipulate social presence.

Visual display

The six experiments that examined the effect of different types of visual display on the sense of presence in collaborative virtual worlds also considered co-presence.

The experiments reported by Axelsson, Schroeder, and Wideström compared the use of a 5-sided Cave and desktop monitor for a Rubik's cube-type task, though Schroeder also included a 4-sided Cave. Unlike the results found for presence, the results for co-presence were inconsistent. Alexsson et al. (2001) and Wideström et al. (2000) found no effect of visual display type, but Schroeder et al. (2001) found a rank ordering based on presence ratings. The 5-sided Cave used with the 4-sided Cave gave the highest ratings, followed by the 4-sided Cave when used with the 5-sided Cave, although there was no statistical difference between these ratings. There was a significant difference between the next highest rating, given for the 5-sided Cave when used with a desktop monitor. Participants who used the desktop monitor gave the lowest co-presence scores. The researchers suggest that these results, taken with the consistent findings favoring a Cave over a desktop monitor for presence, may mean that the co-presence experienced by a partner using a monitor overrides that of the Cave participant. This may be the case, but additional research is needed. If a high level of presence is a requisite for some collaborative task, developers need to know of any potential consequence of using unmatched visual displays. In the extension reported by Heldal et al. (2005), participants in the Cave-to-Cave and Cave-to-HMD conditions reported

significantly more co-presence than those in the Cave-to-desktop monitor and desktop monitor-to-desktop monitor conditions. Also, participants who used the HMDs to view the virtual world reported significantly more co-presence than those who viewed the virtual world using a Cave. These later results provide further evidence that the value of immersive displays, at least under these circumstances, may be reduced when some participants are limited to nonimmersive displays. The researchers also found that ratings of contributions to solving the task and performance ratings were significantly lower when display settings were asymmetrical.

The small-group experiments performed as part of the COVEN project examined the effect of HMD and desktop monitor displays when groups of three participants collaborated to solve word puzzles. Just as those experiments found no effect of visual display type on presence, they also found no effect on co-presence. However, these researchers described several problems that may have limited the amount of collaboration possible between participants. Participants had problems monitoring the activities of other participants while they were acting or navigating in the virtual world, for example, and had problems keeping a referenced shared object and the other participants in the same view.

3.1.2 Consistent Results Across Different Experiments

Table 8 identifies the technical characteristics that showed consistent results across experiments for co-presence or social presence. Most of these experiments provide additional support for the effect of gaze behavior on social presence. One provides data on a different kind of agent identity. As before, relevant experiments already mentioned as replications are repeated in Table 8 (shown in *italics*).

Behavioral realism

Bailenson has reported three additional experiments on gaze behavior that used different experimental tasks. In one experiment, three participants met around a virtual table to play the "20 Questions" game (see Bailenson et al. (2002)). Mutual gaze was compared in a condition where avatars' heads did not move and in a no-avatar condition. In the mutual gaze condition, as before, the avatars with head movements also blinked and moved their mouths when the participant they represented spoke. These participants gave significantly higher ratings for social presence for the more realistically behaving avatars. Participants also looked at each other more, spoke a lower percentage of the time, and gave higher ratings for liking each other when mutual gaze was used.

Table 8. Technical Characteristics With Consistent Findings for Co-Presence and Social Presence

Factor		Description	Significant Relationship	Co-Presence Measure	Type	Experiment Reference
Avatars and agents	Behavioral realism	*Mutual gaze, eyes closed*	*Mutual gaze*	*5-item questionnaire*	*S*	*(Bailenson 2003 (1))*
		Mutual gaze, eyes closed	*Mutual gaze*[9]	*5-item questionnaire*	*S*	*(Bailenson 2003 (2))*
		Gaze (5 levels of realism)	*Mutual gaze*[10]	*5-item questionnaire*	*S*	*(Bailenson 2001a)*
		Inferred gaze, random gaze	*Inferred gaze*[11]	*5-item questionnaire*	*S*	*(Garau 2003)*
		Mutual gaze, no head movement, no avatar	Mutual gaze	3-item questionnaire	S	(Bailenson 2002)
		Static, random, mimic, recorded head movement	Random movement	3-item questionnaire	S	(Bailenson 2004a)
		Gaze behavior (natural, augmented, reduced)	Natural, reduced[12]	7-item questionnaire	S	(Bailenson 2004c)
	Identity	*Tutor, stranger*	–	*5-item questionnaire*	*S*	*(Bailenson 2004b (1))*
		Tutor, stranger	–	*5-item questionnaire*	*S*	*(Bailenson 2004b (2))*
		Other, self	–	*6-item questionnaire*	*S*	*(Bailenson 2001b (1))*

Key: *In the "Type" column, "S" stands for social presence.*

9 Also an interaction with participant gender, with significantly more presence reported by male participants.

10 Also an interaction with participant gender, with females responding significantly more to manipulations of gaze behavior.

11 Also an interaction effect on social presence and on co-presence, with the higher realism avatar used with inferred gaze associated with significantly more presence.

12 Also an interaction with participant gender, with females reporting more significantly presence in the natural condition than males.

Agent head movements that were static, were random, mimicked the participants, or were recorded from a previous trial with another participant were also examined (see Bailenson et al. (2004a)). Here, participants were seated at a table across from an agent. They observed the agent for a short period and approached it to read the label on its chest. Again, gaze behavior had a significant effect on ratings of social presence. None of the head movements in this experiment provided a full mutual gaze, but participants reported significantly more social presence for the random gaze than for the still head movements. This experiment also varied the realism of agent appearance and found an interaction with gaze behavior such that the least presence was reported for a mismatch between the levels of realism used for gaze behavior and agent representation. Cognitive markers of social presence included embarrassment ratings (reported willingness to perform embarrassing acts in front of the agent) and avatar likeability. These showed no relationship with gaze behavior but distinguished between levels of realism used for the agent's appearance. Recall of agent's labels did distinguish between gaze behaviors, with significantly worse recall in the mimic condition, although gaze behavior also interacted with representation. The researchers concluded that while self-report social presence ratings were effective for assessing how an avatar was *perceived*, the other measures provided a better indication of how the participant may *respond*.

Gaze behavior was further manipulated in a sixth, more recent experiment (see Bailenson et al. (2004c)). This time, pairs of participants listened to a reading given by an avatar controlled by an experimenter, pausing at places in the reading to discuss each section. The presenter's avatar reproduced his head movements exactly, directed its gaze at each of the participants all the time (using a non-zero-sum gaze technique), or looked down the entire time. Listeners' head movements were reproduced exactly. All avatars blinked and moved their mouths when that person spoke. Participants who met with avatars that exhibited the presenter's actual gaze or constantly looked down reported significantly higher social presence. Avatars that kept their gaze constantly on a participant were perceived as unnatural and unresponsive. Gaze behavior had no relationship with the results of another memory test used as a cognitive indicator of social presence. The researchers also found that female participants demonstrated significantly more agreement with the contents of the reading matter (i.e., were more persuadable) when the presenter appeared to be looking at them continually. Based on this finding, the researchers hypothesize a distinction between low-level, automatic responses and higher level, reasoned responses. Ways in which other types of avatar behavior tap into instinctive responses remain unknown at this time.

Identity

The two experiments by Bailenson identified in the previous section (see Section 3.1.1) found that the identity verbally assigned by researchers to an avatar influenced participants' behavior in a virtual world, although it had no effect on their ratings of social presence. In another experiment, these researchers examined how participants responded when an avatar they met resembled them (see Bailenson et al. (2001b)). For each participant, an agent that used a 3-D texture mask of that participant's head and face was developed, and its animating behaviors were tied to the texture map. All agents had the same generic cloak-draped bodies. An agent exhibited just two nonverbal behaviors (blinking and head turning) to maintain a gaze at the participant's face. As in other experiments, participants used an HMD and walked freely within the space represented by the virtual world. Here, again, participants were asked to approach the agent, walking to the left side, the right side, and finally to the front of the agent. As the researchers had hypothesized, participants treated their virtual selves more intimately than they treated the unknown agent. They moved closer to their virtual selves, leaving a larger space around the unknown agent. (The size of personal space left around the stranger was the same as that found in previous experiments.) While this difference was significant, again, as before, there was no difference in participants' ratings of social presence in the two situations or in reported positive effect toward the two types of avatars. Similarly, participants in the two groups did not differ significantly in their reported willingness to perform embarrassing acts in front of the avatars.

Together, these experiments indicate that proxemic behavior might be a more sensitive indicator of social presence than the questionnaire that was used, even though the experiments were unable to distinguish between different levels of social presence.

3.1.3 Summary

Replicated experiments have examined three aspects of avatars and agents (gaze behavior, identity, and voice personality) and found a consistent effect on ratings of social presence and co-presence in each case: (1) mutual gaze resulted in higher levels of social presence and co-presence, (2) identity described as a computer tutor or a stranger had no effect on social presence, and (3) matching a synthesized voice personality to participants' personalities increased the sense of social presence. Only the second result was unexpected, and, here, minimum interpersonal distance used as a behavioral indicator of social presence did show a significant difference, suggesting that the social presence questionnaire might have been insufficiently sensitive to pick up the effect. The finding for gaze behavior is supported by three additional experiments. Another experiment, which used agents that represented the participant or some stranger, had the same

findings as the previous work. The social presence questionnaire showed no effect of condition, although proxemic behavior did reveal a significant difference.

Other replicated experiments examined the effect of display type on co-presence. Unlike the case for presence, the use of Caves was not consistently associated with a higher sense of co-presence when participants collaborated in a puzzle-solving task using a Cave display or desktop monitor. Another series of experiments that compared the use of HMDs and desktop monitors on a different collaborative task did have consistent results: the type of visual device was not related to co-presence, as was the case for presence.

Several other aspects of avatar (or agent) representation have been examined in more than a single experiment. Avatar gender had inconsistent results in two experiments, and the perceived agency (human controlled or computer controlled) had inconsistent results in three experiments. Perhaps, most surprisingly, the realism of avatar representation had mixed findings in seven experiments, some of which considered only an avatar's face and others the type of body provided.

Clearly, the potential relationship that different avatar characteristics may have with the sense of co-presence and social presence generates a lot of interest, but research into the effects of other types of technical characteristics is also needed.

3.2. Task Characteristics for Co-Presence and Social Presence

Few experiments have examined the role of task characteristics with respect to co-presence or social presence. One experiment used an agent in a marketing task. Two others examined how the presence of an avatar might influence co-presence if interaction with the avatar was necessary for task performance. These latter two experiments had consistent findings.

In one experiment, Casanueva (2001 (1)) asked participants to navigate a virtual maze and search for colored pyramids, cubes, and rectangles that had to be moved into a room marked for that type of shape. Working in groups of three, participants were represented by simple "T-shaped" avatars of different colors. Shapes could only be picked up by an avatar of the same color. In one experimental condition, each shape had an attached padlock of different color so that two participants had to collaborate, with one clicking to unlock a padlock and another clicking to pick up the shape within 6 seconds. All participants viewed the virtual world using desktop monitors. Participants whose task necessitated collaboration reported significantly more co-presence and gave significantly higher ratings for group collaboration.

The second experiment also used a virtual maze. In this case, either individually or working as a pair, participants played a game where they had to find a way out of the maze while surviving attacks by other characters and animals. Participants were represented in the virtual world as a simple gun and used desktop monitors for their visual display device. Romano et al. (1998) reported that participants who worked in pairs gave significantly higher ratings of co-presence. However, no reported research has considered how hostile characters might affect a user's sense of co-presence. It seems likely that a participant's awareness and reactions to such characters would have had a complex interaction with his response to his partner.

Clearly, much needs be learned about how various task characteristics influence presence. Many, if not all, of those characteristics relevant for presence are also applicable for co-presence and social presence.

4. Conclusions

This document has taken a high-level look at the results of many hours of hard work performed by a large number of researchers. It has not been possible to discuss in detail every experiment that has been mentioned. Also, the experiments covered represent less than half of the work that has investigated presence, co-presence, and social presence constructs.

What, then, can be learned from this body of work? In many cases, the interfaces, virtual worlds, and experimental tasks that have been used in experiments are not representative of likely practical applications and for good reasons—usually to try and avoid factors that might confound results or to stay within the limits of research funding. So, while past research has provided some indications of technical and task characteristics that may have the potential to increase or decrease a user's sense of presence, the findings must be applied cautiously. Findings supported by larger numbers of replicated studies and wider varieties of VEs are most likely to continue to hold. Stereoscopic viewing, FOV, and user interactivity have been examined in five or more experiments that had a consistent result with respect to reported presence. Likewise, five experiments found a consistent result for the relationship between avatar (or agent) gaze behavior and social presence. Four experiments found that visual display update rates had a relationship with the sense of presence, consistently finding that update rates of 20 Hz and higher resulted in more sense of presence than slower update rates.

Although examined under a smaller range of circumstances, consistent results have also been found (in at least two studies) for the relationship between presence and navigation method, the use of texture mapping, avatars and agents that interact with a participant, force feedback for object manipulation, and task difficulty. Using a single VE, spatialized sound, image motion,

presenting a virtual world as a foreground or background image, presentation quality, and scene realism were also related to the sense of presence in replicated experiments. The use of Cave and HMD displays in collaborative tasks resulted in a higher sense of presence than the use of a desktop monitors in one replicated experiment, although no difference was found between the use of HMDs and desktop monitors in another. No relationship was found between the sense of presence and the use of multiple sound sources or self-representation in two additional replicated experiments, whereas inconsistent results were found for sound source rotation.

Factors that may affect co-presence and social presence have been examined less frequently than those that may influence presence. The aforementioned relationship between avatar (or agent) gaze behavior and social presence is the only strongly substantiated finding at this time. Replicated experiments have found consistent results for avatar (or agent) identity and voice personality on social presence. For co-presence, a replicated experiment found a consistent lack of relationship for visual display type (HMD or desktop monitor) for a collaborative task, while another replicated experiment found inconsistent results comparing the use of immersive and nonimmersive displays.

Even though the characteristics of some interface devices will improve with advances in the underlying technologies, rapid near-term improvements are not foreseen. Meanwhile, understanding how constraints imposed by VE technology may affect presence will continue to be needed.

An important point has been made by more than one researcher: When it comes to presence, just adding “more textures, more resolution, or more …” does not necessarily lead to continual increases in presence. Instead, a consistent level of realism has to be presented since mismatches in realism seem to cause a conflict that impedes users’ sense of presence. In addition, there may be a plateau effect, beyond which it is not cost effective to reach for higher levels of presence, although there are no data on this yet.

It would be easy to say that more research is needed to determine where such thresholds might lie. In practice, presence is usually reported in terms of questionnaire scores that only have a relative value for comparing scores when some variable has changed. The meaning of a score in absolute terms is unknown. Therefore, progress in this area will need a better understanding of the presence construct and how to measure it.

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Glossary

1-D	one-dimensional
2-D	two-dimensional
3-D	three-dimensional
6-D	six-dimensional
ACM	Association for Computing Machinery
AEQ	Audio Experience Questionnaire
API	Application Programming Interface
AQ	Acrophobia Questionnaire
AR	augmented reality
ARI	U.S. Army Research Institute for the Behavioral and Social Sciences
ARS	Adjectival Response Scale
B.V.	Besloten Vennootschap (Dutch: Limited Company)
BIP	break in presence
CATT	Computer-Aided Theatre Technique
CE	Computer Experience
CHI	computer-human interaction
COVEN	COllaborative Virtual ENvironments
CRP	Corneal Reflex Pupillometer
CRT	cathode ray tube
CSCW	Computer Supported Cooperative Work
CVE	collaborative virtual environment
DES	Dissociative Experience Scale
DiGRA	Digital Games Research Association
DIVE	Distributed Interactive Virtual Environment
DOF	degree of freedom
DSM-IV	Diagnostic and Statistical Manual of Mental Disorders 4th Edition
E^2I	Engagement, Enjoyment, and Immersion

EKG	electrocardiogram
FOV	field of view
fps	frames per second
GE	General Electric Corporation
GFOV	geometric field of view
GSR	Galvanic Skin Reflex
HAH	Hanchey Army Heliport
HAZMAT	hazardous material
HFOV	horizontal field of view
HMD	head-mounted display
HRP	Halden Reactor Project
HRTF	Head-Related Transfer Function
HRV	heart rate variability
IBM	International Business Machines Corporation
ICAT	International Conference on Artificial Intelligence and Telexistence
ICEC	International Conference on Entertainment Computing
IDA	Institute for Defense Analyses
IIS	Institut für Integrierte Schaltungen
IMI	Intrinsic Motivation Inventory
IPD	Inter-Pupiliary Distance
IPO	Center for User-System Interaction, Department. of Technology Management, Eindhoven University of Technology
IPQ	Igroup Presence Questionnaire
IPT	immersive projection technology
IR	infrared
ISDN	Integrated Services Digital Network
ITC-SOPI	Independent Television Commission-Sense of Presence Inventory
ITQ	Immersive Tendencies Questionnaire
JAVA	A general purpose, high-level, object-oriented, cross-platform programming language developed by Sun Microsystems
JISC	Joint Information Systems Committee
JTAP	JISC Technology Applications Programme

LAN	local area network
LCD	Liquid Crystal Display
M.I.N.D.	Media Interface and Network Design
M.Sc.	Master of Science
MCQ	Memory Characteristic Questionnaire
MEC	Measures, Effects, Conditions
MEQ	Media Experience Questionnaire
MSQ	Motion Sickness Questionnaire
MSSS	Motion Sickness Susceptibility Survey
MST	Motion Sickness Tendency
NASA	National Aeronautics and Space Administration
NAVE	Non-expensive Automatic Virtual Environment
NLP	Neurolinguistic Programming
NTU	Nanyang Technological University
OECD	Organisation for Economic Co-operation and Development
OpenGL	Open Graphics Laboratory
OPQ	Object Presence Questionnaire
PANAS	Positive Affect Negative Affect Schedule
PC	personal computer
PDA	Personal Digital Assistant
Ph.D.	Doctor of Philosophy
PLUM	Programme on Learner Use of Media
POC	point of contact
POEMS	Perceptually Oriented Ego-Motion Simulation
PQ	Presence Questionnaire
PRCS	Personal Report of Confidence as a Public Speaker
PVE	purely virtual environment
RAM	random access memory
RAT	Robust Audio Tool
RE	Real Environment
RJPQ	Reality Judgment and Presence Questionnaire
SAD	Social Avoidance and Distress

SAGAT	Situation Awareness Global Assessment Technique
SGI	Silicon Graphics, Inc.
SIGCHI	Special Interest Group for Computer-Human Interaction
SIGGRAPH	Special Interest Group on Computer Graphics
SPQ	Social Presence Questionnaire (e.g., IPQ-SPQ) Spatial Presence Questionnaire (e.g., MEC-SPQ)
SSC	Short Symptom Checklist
SSQ	Simulator Sickness Questionnaire
STRATA	Simulator Training Research Advanced Testbed for Aviation
SUD	Subjective Units of Discomfort
SUS	Slater-Usoh-Steed
SVE	Shared Virtual Environment Simple Virtual Environment
SVUP	Swedish User-Viewer Presence Questionnaire
TAS	Tellegen Absorption Scale
TLX	Task Load Index
TR	Technical Report
TV	television
UCL	University College London
UKVRSIG	UK Virtual Reality Special Interest Group
UNC	University of North Carolina
UV	ultraviolet
VAS	Visual Analogue Scale
VE	virtual environment
Ve^2	Virtual Engineering Environment
VEPAB	Virtual Environment Performance Assessment Battery
VERTS	Virtual Emergency Response Training System
VFHE	visually faithful hybrid environment
VGA	Virtual Guiding Avatar
VR	virtual reality
VRAIS	Virtual Reality Annual International Symposium
VRML	Virtual Reality Modeling Language

VRST	Virtual Reality Software and Technology
VRT	Voice Recognition Technology
VRUSE	a VR usability technique (a diagnostic tool)
WAN	wide area network

Appendix

Summaries of Experimental Studies

Appendix

Summaries of Experimental Studies

Note for the Appendix

In the discussion of the experiments, the *italicized* items (except for paper Titles) do not relate directly to Presence (e.g., Findings (7)–(11) for the first experiment listed [Allen 2001]).

[Allen 2001] Allen, R.C. and M.J. Singer. 2001. *Presence in Altered Environments: Changing Parameters and Changing Presence*. U.S. Army Research Institute for the Behavioral and Social Sciences, Orlando, FL.

Factors:	Field of view (FOV) (virtual 48º × 36º, real Restricted 48º × 36º, real Horizontal Visual Field 96º × 36º, real Lower Visual Field 48º × 72º, real Normal), self-representation (body, right hand and fanny pack when 2 ft. from a trashcan).
Computing platform:	Silicon Graphics, Inc. (SGI) Onyx RealityEngine2 with eight 200-MHz R4400 processors, 256 MB random access memory (RAM). Software Systems Multigen II v1.5 and in-house software.
Visual display:	For Virtual Environment (VE): Virtual Research Corp., V8 head-mounted display (HMD) with FOV 48º × 36º and 1820 × 480 color pixels per eye. Participant eye height and Inter-Pupiliary Distance (IPD) used to adjust display. For real world: HMD, mockup with plastic goggles, including cardboard cutouts for masks.
Auditory display:	Sound of collisions and white noise presented over HMD headphones.
Tracking:	For VE: Head, shoulder, feet, right arm, and right hand motions using 6 Ascension Technologies Flock-of-Birds sensors and tracked by an Ascension Technologies MotionStar (wired version) with an extended range transmitter. For real world: Precision Navigation Inc. TCM2/50 Electronic Compass Module mounted on HMD mockup.
Navigation:	Walking in place.
Object manipulation:	In VE, used joystick to move virtual hand close to fanny pack and pick up then drop a virtual ball. In real world, used real balls carried in a fanny pack.
Virtual world:	Series of 3 rooms filled with typical office furniture. Self-representation as virtual body or virtual right hand (and fanny pack).
Training:	Movement training in 2 separate practice environments, included general movement (VE condition only), collision avoidance, path following. Then, in 1 practice environment, search training that involved locating 2 trashcan targets in sequential order and dropping a ball inside each.
Experimental task:	For guided movement task, in first room, follow a path defined by arrows as quickly and accurately as possible, minimizing collisions. For search task, in each remaining room, search for 2 trashcan targets in sequential order and drop a ball inside each.
Participants:	90 participants recruited from a university campus; 36 males; age range 18 to 45; mean age 21 yr.
Study design:	Between-subjects.
Presence measures:	32-item Witmer-Singer Presence Questionnaire (PQ) Version 3.0.
Person-related meas.:	Immersive Tendencies Questionnaire (ITQ). *Motion Sickness Questionnaire (MSQ).*
Task-related measures:	Simulator Sickness Questionnaire (SSQ).
Performance measures:	Guided movement time, number of collisions, search time.
Other measures:	Head movement (yaw, pitch).

Findings:

(1) Self-representation had a significant effect on presence only for PQ Natural subscale, with users rating disembodied condition as more natural than avatar condition.

(2) Comparing virtual (48º × 36º) with matching real (48º × 36º) FOV had a significant effect on PQ Total and all except Natural subscale scores, with VE users reporting significantly more presence than Restricted-condition users.

(3) FOV in real world had a significant effect on PQ Total and all PQ subscales except Involved/Control subscale, where Normal group rated Interface Quality higher than Restricted and Lower Visual Field groups, and Normal group rated total PQ, Naturalness, and Resolution higher than Restricted group.

(4) For real-world participants, FOV had a significant positive correlation with PQ Total and Natural, Interface Quality, and Resolution subscales.

(5) For VE participants, ITQ Focus subscale scores had a significant positive correlation with PQ Total, Involved/Control and Interface Quality subscale scores, and ITQ Games subscale scores had a significant positive correlation with PQ Total and Involved Control subscale scores. For real-world participants, ITQ Games subscale scores had a significant positive correlation with PQ Resolution subscale scores.

(6) For VE participants, SSQ Total score had a significant negative correlation with PQ Total and Involved Control subscale scores; SSQ Oculomotor Discomfort with PQ Total, Involved/Control, and Natural subscales; and SSQ Disorientation with PQ Natural subscale. For real-world participants, SSQ Total and subscale scores had no significant correlations with PQ Total and subscale scores.

(7) For the guided movement task, self-representation had a significant effect on time taken, with the Body group taking significantly longer. Time taken by the disembodied group also was significantly different from time taken by the Restricted group. Self-representation had no significant effect on collision score or head movement. In each case the score for the (pooled) VE groups differed significantly from that of the Restricted group.

(8) For the search task, self-representation had no significant effect on time taken, collision score, or head movement. In each case, the score for the (pooled) VE groups differed significantly from that of the Restricted group.

(9) Self-representation had no significant effect on pitch or yaw or on change (pre, post exposure) in SSQ Total or subscale scores.

(10) Type of environment/FOV showed a significant effect on post-exposure SSQ scores between the (pooled) VE and (pooled) real-world groups only, with VE participants reporting significantly higher SSQ Total score, and higher Nausea, Oculomotor Discomfort, and Disorientation subscale scores.

(11) For VE participants, SSQ scores had a significant positive correlation with MSQ Total, subscale A, and subscale B with SSQ Disorientation.

[Axelsson 2001] Axelsson, A.-S., Å. Abelin, I. Heldal, R. Schroeder, and J. Wideström. 2001. "Cubes in the Cube: A Comparison of a Puzzle-Solving Task in a Virtual and a Real Environment." *CyberPsychology & Behavior*, 4(2), 279–286.

Factors:	Visual display (1 participant in 5-sided Cave and 1 using desktop system).
Computing platform:	SGI Onyx 2 Infinite Reality with 14 MIPS R10000 processors, 2 GB RAM, 3 graphics pipes. SGI O2 with 1 MIPS R10000 processor, 256 MB RAM. DVise 6.0 software with SGI Performer renderer.
Visual display:	3 × 3 × 3 m TAN three-dimensional (3-D) Cube with projection on 5 walls (no ceiling), stereoscopic viewing using Stereographic Corp. Crystal Eyes shutter glasses. 19-in. monitor with FOV ~ 60°. Frame rate ≥ 30 Hz.
Auditory display:	Communication via telephone headset.
Tracking:	Polhemus tracker attached to shutter glasses.

Navigation:	In the Cube system: by moving around physically and gesturing with DVise 3-D mouse. In the desktop system: by moving middle button on standard 3-button two-dimensional (2-D) mouse.
Object manipulation:	In the Cube system: blocks selected and moved by a participant putting his hand into a virtual cube and pressing 3-D mouse button. In the desktop system: blocks selected by clicking on the cube with the left button, then moved by keep right button pressed and moving the mouse; cubes rotated using a combination of the right mouse button and shift key.
Virtual world:	Empty room containing 8 blocks with 1 of 6 different colors on each side. Blocks were 30 cm each edge. Self-representation as identical dVise avatars.
Experimental task:	Two participants cooperate to solve a puzzle by arranging blocks into a cube such that each side of the completed cube displays a single color. 20-min. time limit.
Participants:	Twenty-two pairs of participants; 26 males; mean age 34 yr.
Study design:	Between-subjects.
Presence measures:	2-item presence questionnaire, 1-item place-to-visit rating, 2-item Co-presence Questionnaire.
Task-related measures:	*2-item questionnaire on own and partner's contribution to task, 1-item on amount of verbal communication, 1-item on extent of collaboration.*
Findings: (1)	Visual display had a significant effect on presence, with CAVE users reporting more presence, but had no significant effect on co-presence.
(2)	Co-presence had a significant positive correlation with presence in the desktop environment but not in the Cave environment.
(3)	*Visual display had a significant effect on contribution, with increased contribution reported for Cave display.*
(4)	*Visual display had no significant effect on amount of communication.*
(5)	*Visual display had no significant effect on collaboration between Cave and desktop system but had a significant effect for Real Environments (Res) and VEs, with more collaboration reported for an RE.*

[Axelsson 1999] Axelsson, A.-S., Å. Abelin, I. Heldal, A. Nilsson, R. Schroeder, and J. Wideström. 1999. "Collaboration and Communication in Multi-User Virtual Environments: A Comparison of Desktop and Immersive Virtual Reality Systems for Molecular Visualization." In *Proc. 6th UKVRSIG Conference*, 13–15 September, University of Salford, UK. 107–117.

Factors:	Visual display (5-sided Cave, desktop).
Computing platform:	Cave system used SGI Onyx2 Infinite Reality with 8 MIPS R10000 processors, 2 GB RAM, 3 graphics pipes. SGI O2 with 1 MIPS R10000 processor, 256 MB RAM. DVise 6.0 software with SGI Performer renderer, Lake Huron 3.0 for audio. Frame rate 4–6 Hz. Desktop system used SGI O2s with 1 MIPS R10000 processor and 256 MB RAM. Frame rate 3–4 Hz.
Visual display:	3 × 3 × 3 m TAN 3-D Cube with projections on 5 walls (no ceiling), stereoscopic viewing using Stereographics Corp. CrystalEyes shutter glasses; frame rate 4–6 Hz. 19-in. monitor.
Auditory display:	8 loudspeakers and a Vibrafloor used in the Cave system.
Tracking:	Polhemus tracker attached to shutter glasses.
Navigation:	In the Cube system: using dVise 3-D mouse. In the desktop system: by moving middle button on standard 2-D mouse.
Object manipulation:	Use of a mouse button to mark objects in the desktop system.
Virtual world:	Open space containing ball-and-stick molecular models of similar size (1,200 atoms); Myoglobin in Cube system and Cytochrome-2 in desktop system. Unique sounds associated with the amino acids and iron atom in the Cave system. Desktop system allowed highlighting a molecule.
Training:	Demonstration and practice in how to navigate and manipulate objects in the VE and how to communicate with partner. 5–10 min.

Experimental task: First, locate the single iron atom within the molecule and identify the atoms connected to it. Then, count the number of carbon rings in the molecule. 15 min. allowed for each task. Questionnaire completed after each task.

Participants: 100 undergraduates, working in groups of 4 to 6 in the Cave-type display and in pairs with the desktop system. Data for co-presence, collaboration, and communication were collected for only the navigator and his collaborator in the Cube system (40 participants). Other participants were bystanders.

Study design: Within-subject.

Presence measures: 2-item presence questionnaire, 1-item Co-presence Questionnaire.

Task-related measures: 1 item on extent of experienced collaboration, 1 item on naturalness of communication, *1 item on leadership, 1 item on pleasantness, 1 item on enjoyment*.

Findings:

(1) Visual display had a significant effect on presence, with Cave users reporting more presence, but no significant effect on co-presence.

(2) In the immersive system, presence had a significant positive correlation with co-presence and collaboration but not with communication. In the desktop system, no significant correlations between presence and any of co-presence, collaboration, or communication.

(3) In both systems, co-presence had a significant positive correlation with collaboration but not with communication.

(4) Visual display had no significant effect on communication, collaboration, or leadership.

(5) Visual display had a significant effect on rating of pleasantness and enjoyment, with increases in each found for the Cube display.

(6) Collaboration had a significant positive correlation with communication for both types of display.

[Bailenson 2004a] Bailenson, J.N., K. Swinth, C. Hoyt, S. Persky, A. Dimov, and J. Blascovich. 2004a. “The Independent and Interactive Effects of Embodied Agent Appearance and Behavior on Self-Report, Cognitive, and Behavioral Markers of Co-presence in Immersive Virtual Environments.” Presented at the 54th Annual International Communication Association Conference, 27–31 May, New Orleans, LA.

Factors: Representation type (human, teddy bear, blockhead), behavioral realism (static head movement, random movement, mimic movement, recorded movement).

Computing platform: 450-MHz Pentium III dual processor with Evans and Sutherland Tornado 3000 dual pipe graphics card, average frame rate 36 Hz., latency < 65 ms. Software Wizard 2.0 with human representation developed using 3-DMeNow.

Visual display: Virtual Research V8 stereoscopic HMD, 680 × 480 resolution, 50° × 38° visual field.

Tracking: Head-tracking using Intersense IS300. System latency 65 ms.

Navigation: Logitech RumblePad Pro input device.

Object manipulation: Logitech RumblePad Pro input device.

Virtual world: Participant seated at a table facing an embodied agent with head and shoulders visible. Agent portrayed photorealistically, with preset blinking pattern but no facial gestures. 8 letters and numbers were shown on a label placed on agent’s chest. No self-representation.

Training: Instruction on how to wear HMD and how to use the game pad.

Experimental task: Once seated across from agent, use game pad to scroll through instructional text that appeared above agent’s head. Observe agent for 90 sec. and then, answer questionnaires. Next, approach agent and examine further.

Participants: 146 undergraduates; 73 males; age range 18 to 27; mean age 19.6 yr.

Study design: Between-subjects.

Presence measures: 3-item Co-presence Questionnaire, minimum interpersonal distance and reversal count in approaching agent.

Task-related measures: Recall of characters on agent’s label, affect rating for avatar, willingness to perform embarrassing actions rating (used as co-marker for co-presence).

Findings:

(1) Behavioral realism had a significant effect on Co-presence Questionnaire scores, with more co-presence reported for the random head movement condition as compared with the static head movement condition. Within the blockhead condition, co-presence was significantly higher for random head movement than for static or mimic head movement. Within the teddy bear condition, co-presence was significantly higher for mimic head movements than for either static or recorded head movements; and significantly higher in the random head movement than for static or recorded head movements.
(2) Co-presence Questionnaire scores had a significant negative correlation with willingness to perform embarrassing acts and a significant positive correlation with likeability.
(3) Co-presence Questionnaire scores had no significant correlation with memory scores.
(4) Co-presence Questionnaire scores had no significant correlation with either interpersonal distance or reversal count.
(5) Representation type had a significant effect on willingness to perform embarrassing acts in front of the embodied agent, with participants in the human condition less willing than those in the teddy bear condition.
(6) Representation type had a significant effect on likeability, with participants in both the human and teddy bear conditions reporting more likeability than those in the blockhead condition.
(7) Behavioral realism had a significant effect on memory, with worse memory for the mimic condition than for either the static or random movement conditions. In the blockhead condition, memory was better in the random movement condition than in either the mimic or recorded conditions. Within the human condition, memory was worse for mimic and random movement conditions than for static or recorded conditions.
(8) Behavioral realism had no significant effect on interpersonal distance.
(9) Representation type had no significant effect on interpersonal distance.
(10) Behavioral realism had a significant effect on reversal count, with participants in the random head movement condition performing significantly fewer reversals that participants in any of the other head movement conditions, which did not significantly differ.

[Bailenson 2004b (1)] Bailenson, J.N., E. Aharoni, A.C. Beall, R.E. Guadagno, A. Dimov, and J. Blascovich. 2004b. "Comparing Behavioral and Self-Report Measures of Embodied Agents' Social Presence in Immersive Virtual Environments." Presented at the 7th Annual Workshop on Presence, 13–15 October, Valencia, Spain.

Factors:	Identity (tutor, stranger).
Computing platform:	Dual pipe Open Graphics Laboratory (OpenGL) PC graphics updated at 60 Hz. Average latency 55 ms.
Visual display:	HMD.
Tracking:	6 degree of freedom (DOF) head-tracking using Intersense IS300, video position tracking using WorldViz PPT.
Navigation:	Real movement.
Object manipulation:	None.
Virtual world:	Open space containing a stationary agent with a label containing one word in his chest. Explorable space 2.6 × 2.5 × 2.5 m. Participants' eye height matched to eye height of agent.
Training:	Interacted with a text-based tutoring algorithm. In second part, presented with a series of 20 facts about American culture and later tested on these facts. Then, entered virtual world and instructed on navigation with ~ 1 min. practice in walking.

Experimental task:		Approach virtual agent from left side, right side, and then to the front and center. Read aloud label on front of agent. 2 trials. Participants were told that either the agent was an embodiment of the computer tutor with whom they had previously worked or a represented an unknown computer algorithm.
Participants:		72 psychology students; 36 males; age range 15 to 30, median age 20 yr.
Study design:		Between-subjects.
Presence measures:		5-item Co-presence Questionnaire, minimum interpersonal distance.
Person-related meas.:		Gender.
Task-related measures:		2-item Likeability Questionnaire, 3-item Status Questionnaire, 2-item Interest Questionnaire (used as markers of co-presence).
Findings:	(1)	Identity had no effect on co-presence.
	(2)	Co-presence had no significant correlation with interpersonal distance.
	(3)	Gender had no significant effect on interpersonal distance or co-presence.
	(4)	On the first trial only, identity had a significant effect on interpersonal distance, with participants leaving more personal space around the tutor.
	(5)	Identity had no significant effect of any of likeability, status, or interest.

[Bailenson 2004b (2)] Bailenson, J.N., E. Aharoni, A.C. Beall, R.E. Guadagno, A. Dimov, and J. Blascovich. 2004. "Comparing Behavioral and Self-Report Measures of Embodied Agents' Social Presence in Immersive Virtual Environments." Presented at the 7th Annual Workshop on Presence, Valencia, Spain.

Factors:		Identity (tutor, stranger).
Computing platform…		
Experimental task:		As in [Bailenson 2004 (1)], except participants performed 6 trials.
Participants:		48 psychology students; 27 males; age range 18 to 23, median age 19 yr.
Study design:		Between-subjects.
Presence measures:		5-item Co-presence Questionnaire, minimum interpersonal distance.
Person-related meas.:		Gender.
Task-related measures:		2-item Likeability Questionnaire (used as a marker of co-presence).
Findings:	(1)	Identity had no effect on co-presence.
	(2)	Co-presence had no significant correlation with interpersonal distance.
	(3)	Gender had no significant effect on interpersonal distance or co-presence.
	(4)	Identity had a significant effect on the average interpersonal distance, with participants approaching the tutor leaving a larger interpersonal distance.
	(5)	Identity had no significant effect on likeability.

[Bailenson 2004c] Bailenson, J.N., A.C. Beall, J. Blascovich, J. Loomis, and M. Turk. 2004. "Non-Zero Sum Gaze and Persuasion." Presented at the 54th Annual Conference of the International Communication Association, May 27–31, New Orleans, LA.

Factors:	Participant gender (male, female), presenter gaze (natural, augmented, reduced).
Computing platform:	Intel Pentium III with 450-MHz dual processor, Evans and Sutherland Tornado 3000 graphics cards.
Visual display:	Virtual Research V8 stereoscopic HMD with 680 × 480 resolution, FOV 50° H × 38° V at full 100% overlap. Scene rendered at ~ 60 Hz, with latency < 65 ms.
Audio display:	Worn full-duplex intercom device.
Tracking:	Head-tracking.
Navigation:	None.
Object manipulation:	Game pad used to record responses.
Virtual world:	Room containing a round table around which 3 avatars were seated. In the natural condition, the presenter's avatar reproduced his gaze at each of the 2 participants; in the augmented condition, the presenter's gaze was directed at both other participants 100% of the time. In the reduced condition, the presenter's gaze looked down at his monitor 100% of the time. Listeners' head movements were

		reproduced exactly. All avatars blinked and moved their lips when that participant spoke. Participants could see own torsos, as appropriate.
Training:		In virtual world, presenter facilitated introductions and discussed how the immersive collaborative virtual environment (CVE) and game pad worked.
Experimental task:		Participate in a discussion with a presenter (experimenter) and one other listener. Presenter read a persuasive passage in 4 sections, leading a discussion after each section for ~ 90 sec. After passage read, the presenter verbally administered 3 Likert-scale agreement questions and 3 recall multiple-choice questions about the passage. Participants responded using game pad.
Participants:		72 introductory psychology students; age range 18 to 25; mean age 19.6 yr.
Study design:		Between-subjects.
Presence measures:		7-item Social Presence Questionnaire.
Task-related measures:		*Average agreement score*; *estimation of percent time presenter was looking at this participant*, *other participant*, *no one*; *written paragraphs about presenter, other participant, and virtual conference*. Memory score (used as a cognitive marker of social presence).
Findings:	(1)	Participant gender had no significant effect on social presence.
	(2)	Presenter gaze had a significant effect on social presence, with participants in the augmented condition reporting less presence than those in the other conditions. Also, participant gender and presenter gaze had a significant interaction, with female participants reporting more presence in the natural condition than did male counterparts.
	(3)	*Gaze direction (toward participant answering question vs. toward other participant) had a significant effect on gaze estimation percent, with participants indicating that they received more of presenter's gaze than the "other" participant did. Participant gender and presenter gaze had no significant effect on gaze estimation percent. Presenter gaze and gaze direction had a significant interaction, with participants in the augmented condition perceiving more gaze directed at themselves as compared with the other two presenter gaze conditions.*
	(4)	*Participant gender and presenter gaze had no significant effect on total gaze (summation of 3 estimation percentages).*
	(5)	*Participant gender had a significant effect on agreement, with females agreeing less overall than males. Presenter gaze had a significant effect on agreement, with agreement in the augmented condition higher than in the other conditions. Gender and gaze had a significant interaction, with females in the augmented condition demonstrating higher agreement than in the other gaze conditions, while males did not show a difference between conditions.*
	(6)	Participant gender had a significant effect on recall, with males scoring higher. Presenter gaze had no significant effect on recall.

[Bailenson 2003 (1)] Bailenson, J.N., J. Blascovich, A.C. Beall, and J.M. Loomis. 2003. "Interpersonal Distance in Immersive Virtual Environments." *Personality and Social Psychology Bulletin*, 29, 1–15.

Factors:	Virtual human gender (male, female), gaze behavior (mutual gaze, eyes closed), participant gender (male, female), agency (human-controlled avatar, computer-controlled agent).
Computing platform:	450-MHz Pentium III dual-processor, with Evans and Sutherland Tornado 3000 dual-pipe graphics card. System latency maximum of 65 ms.
Visual display:	Virtual Research V8 stereoscopic HMD with resolution 680 × 480, FOV 50º H × 38º V. Frame rate 36 Hz. Participant eye height used to adjust display.
Tracking:	Head-tracking using Intersense IS300 and in-house passive optical position sensing system.
Navigation:	Actual walking.
Object manipulation:	None.

Virtual world:	7.2 × 6.4 × 4.5 m textured floor. Mutual gaze was indicated by appropriate head movements of the avatar and occasional blinking; otherwise, the avatar's head was stationary and the eyes closed. Shirt of virtual human had a label on the front depicting a name and a label on the back giving numbers. Participant eye height set at ~ 1.7 m. Participant not represented. No collision detection.
Training:	Exploration of an empty room for approximately 1 min.
Experimental task:	Move through a series of rooms to find a stationary person with shirt bearing labels on front and back. Walk to the person and read the back label and then the front label. 5 trials in each block varying in virtual human details. 2 blocks of trials, 1 with female virtual human, 1 with male. After trials and completing recall test, participants redonned the HMD to complete Social Presence Questionnaire while in virtual world.
Participants:	80 introductory psychology students; age range 18 to 30; mean age 19.6 yr.
Study design:	Within-subjects for virtual human gender, between-subjects for gaze behavior, participant gender, and agency.
Presence measures:	5-item Social Presence Questionnaire, minimum interpersonal distance.
Task-related measures:	*Affect rating for liking of virtual humans.*
Performance measures:	*Recall test on names and numbers on patches; matching test on names and number.*
Findings:	(1) Gaze behavior had a significant effect on social presence, with higher presence scores for mutual gaze.
	(2) Virtual human gender, participant gender, and agency had no significant effect on social presence.
	(3) Virtual human gender had a significant effect on minimum distance; more presence reported for male virtual human. Gaze behavior, participant gender, and agency had no significant effect on minimum distance. Gaze behavior and agency had a significant interaction, with minimum distance greater from agents with head movement and blinking than agents without. Participant gender and agency had a significant interaction, with minimum distance greater for female participants.
	(4) Social presence had no significant correlation with minimum interpersonal distance.
	(5) Virtual human gender only had a significant effect on liking of virtual human, with participants liking the male virtual human more.
	(6) Agency only had a significant effect on memory, with higher recall for names and numbers on avatars than for those on agents.

[Bailenson 2003 (2)] Bailenson, J.N., J. Blascovich, A.C. Beall, and J.M. Loomis. 2003. "Interpersonal Distance in Immersive Virtual Environments." *Personality and Social Psychology Bulletin*, 29, 1–15.

Factors:	Virtual human gender (male, female), gaze behavior (mutual gaze, eyes closed), participant gender (male, female), agency (human-controlled avatar, computer-controlled agent), contact time (before contact, after contact).
Computing platform:	Object manipulation: As in [Bailenson 2003 (1)].
Virtual world:	7.2 × 6.4 × 4.5 m space with no walls or ceiling, but floating bar used to indicate presence of physical room walls. Participant eye height set at ~ 1.7 m. No self-representation. No collision detection.
Navigation:	Actual walking.
Training:	Exploration of empty room for approximately 1 min.
Experimental task:	Approach left side virtual, then across front of virtual human to right side, then to front to read a Likert-type scale positioned over virtual human's head. (Social Presence and Affect Questionnaires administered at this time.) Return to starting point and stand while approached by virtual human. Virtual human moved through participant. 2 blocks of 5 trials, each trial 5 to 10 min. (Emotional Reaction Questionnaire administered.)
Participants:	80 introductory psychology students; age range 18 to 25; mean age 19.6 yr.

Study design:		Within-subject for virtual human; between-subjects for gaze behavior, participant gender, and agency.
Presence measures:		5-item Social Presence Questionnaire, minimum interpersonal distance.
Task-related measures:		Affect rating for avatar, Emotional Reaction Questionnaire (used as co-markers for co-presence).
Findings:	(1)	Virtual human gender had a significant effect on social presence, with more presence reported for male virtual human. Virtual human gender had a significant interaction with agency, with more presence reported for male avatars.
	(2)	Gaze behavior had a significant effect on social presence, with more presence reported for mutual gaze. Gaze behavior had a significant interaction with participant gender, with more presence reported for male participants.
	(3)	Agency had a significant effect on social presence, with more presence reported for avatars.
	(4)	Contact time had a significant effect on minimum interpersonal distance, with greater distances left after the virtual human passed through the participant.
	(5)	Participant gender had no significant effect on social presence.
	(6)	Agency had a significant effect on minimum interpersonal distance, with more distance for agent. Virtual human gender, gaze behavior, and participant gender each had no significant effect on minimum interpersonal distance.
	(7)	Virtual human gender, gaze behavior, participant gender, and agency had no significant effect on liking of virtual human.
	(8)	Emotional reaction scores had a significant positive correlation with maximum avoidance distance.

[Bailenson 2002] Bailenson, J.N., A.C. Beall, and J. Blascovich. 2002. "Gaze and Task Performance in Shared Virtual Environments." *Journal of Visualization and Computer Animation*, 13, 313–320.

Factors:		Behavioral realism (mutual gaze, no head movement, no avatar).
Computing platform:		Intel Pentium III with 450-MHz dual processor, Evans and Sutherland Tornado 3000 graphics cards.
Visual display:		3 Virtual Research V8 stereoscopic HMDs with 680 × 480 resolution, 60º diagonal FOV, 36-Hz frames per second (fps) rate with latency < 65 ms.
Audio display:		Auditory headset worn over HMD, with microphone.
Tracking:		Head-tracking.
Navigation:		None.
Object manipulation:		None.
Virtual world:		Room where three participants met around a common table. Avatar head movements were used to show direction of participants' gaze and were accompanied by blinking and mouth movements. Participants unable to see own avatar.
Experimental task:		In groups of three, play "20 questions" game. One participant in each trial always answerer, with other two asking questions. 3 blocks of 3 trials (questionnaire completed after each block).
Participants:		27 undergraduate psychology students; 16 males.
Study design:		Within-subjects.
Presence measures:		10-item presence questionnaire, including 3 items on social presence.
Task-related measures:		*Average time individual participants spent speaking, head orientation*.
Performance measures:		*Number of questions asked per game, average time to finish a game*.
Findings:	(1)	Behavioral realism had a significant effect on total questionnaire scores and on 2 social presence items, with most presence reported for the more realistic avatars.
	(2)	*Behavioral realism had a significant effect on time participants spent speaking, with least speaking with more realistic avatars and more speaking when no avatars were present. Had no significant effect on number of questions asked or average time to finish a game.*
	(3)	*Behavioral realism had no significant effect on head orientation.*

[Bailenson 2001a] Bailenson, J.N., J. Blascovich, A.C. Beall, and J.M. Loomis. 2001. "Equilibrium Theory Revisited: Mutual Gaze and Personal Space in Virtual Environments." *Presence*, 10(6), 583–598.

Factors:	Character realism (photographic texturing face, flat shaded face), behavioral realism (mutual gaze with eye dilation when participant stepped within 0.75 m, mutual gaze, eyes open and blinking, eyes open, eyes closed), participant gender (male, female).
Computing platform:	450-MHz Pentium III dual-processor, with Evans and Sutherland Tornado 3000 dual-pipe graphics card. System latency < 65 ms.
Visual display:	Virtual Research V8 stereoscopic HMD with resolution 680 × 480, FOV 50º H × 38º V. Frame rate 36 Hz. Participant eye height used to adjust display.
Tracking:	Head-tracking using Intersense IS300 and in-house passive optical position sensing system.
Navigation:	Walking around.
Object manipulation:	None.
Virtual world:	7.2 × 6.4 × 4.5 m room with either a pylon or an agent standing inside. Agent represented as a Caucasian male, 3-D polygonal model, 1.85 m tall, and wearing a label on the front on the front on his shirt giving his name and a back label listing a number, both in text easily readable from 1 meter. Different colored shirt and hair and different name and number for each trial. Mutual gaze included periodic blinking. No collision detection. No self-representation. In control condition, a pylon replaced the agent, same height as agent, with color and labels changing. 2 blocks of 5 trials, with each block taking 5 to 15 min.
Training:	Walking around empty virtual room for approximately 1 min.
Experimental task:	Walk toward agent and read number on back of shirt, then name on front. After completing recall test, participant redonned an HMD to complete Social Presence Questionnaire while in virtual world.
Participants:	50 participants; 26 males; age range 18 to 31. 10 participants used in control condition with pylon.
Study design:	Within-subjects for face model, between-subjects for gaze behavior, gender.
Presence measures:	5-item Social Presence Questionnaire, minimum interpersonal distance.
Person-related meas.:	Gender.
Performance measures:	*Percent correct when matching of names to numbers for recall test. (Results almost identical to those for minimum interpersonal distance, also highly correlated with minimum interpersonal distance.)*

Findings:

(1) Character realism and gender had no significant effect on social presence (excluding control condition).

(2) Behavioral realism had a significant effect on social presence for females only, with more presence reported for mutual gaze.

(3) Character realism had a significant effect on minimum interpersonal distance, with larger distance maintained for agent conditions. Gender had a significant interaction effect with character realism on interpersonal distance, with females maintaining more distance when agents used mutual gaze.

(4) Behavioral realism had a significant effect on minimum interpersonal distance for females only, with more distance left more distance for a mutual gaze.

(5) Character realism had a significant effect on memory test scores when the control condition was considered, with the pylon giving better scores.

(6) Realism of face model, behavioral realism, and gender each had no significant effect on memory test.

[Bailenson 2001b (1)] Bailenson, J.N., A.C. Beall, J. Blascovich, M. Weisbuch, and R. Raimmundo. 2001. “Intelligent Agents Who Wear Your Face: Users’ Reactions to the Virtual Self.” In A. de Antonio, R. Aylett, and M. Weisbuch (Eds.), *Intelligent Virtual Agents*, 86–99.

Factors:	Agency (avatar of self, avatar of other).
Computing platform:	450-MHz dual-processor Intel Pentium III-based PC, with Evans and Sutherland Tornado 3000 video adapter. OpenGL-based software rendering.
Visual display:	Virtual Research V8 stereoscopic HMD with 680 × 480 resolution, FOV 60° diagonal. Frame rate 36 Hz, with latency < 65 ms.
Audio display:	None.
Tracking:	Orientation and position tracking.
Navigation:	Walking in 3 × 3 m area.
Object manipulation:	None.
Virtual world:	Open area containing an avatar with a detailed head and generic body covered by a loose robe. Avatars had head movements and blinking eyes. Virtual eye height set to 1.7 m.
Experimental task:	Walk to the left side of the embodied agent, then to the right side, and then to the front of the agent.
Participants:	16 introductory psychology students.
Study design:	Between-subjects.
Presence measures:	6-item Social Presence Questionnaire, minimum distance in approaching agent.
Task-related measures:	Affect rating for avatar, willingness to perform embarrassing actions rating (used as co-markers for co-presence).
Findings: (1)	Agency had no significant effect on social presence.
(2)	Agency had a significant effect on minimum distance, with less distance for avatars with the participant’s head.
(3)	Agency had no significant effect on affect rating, but a significant effect on willingness to perform an embarrassing, with increased willingness with an avatar with the participant’s head.

[Bailey 1994 (2)] Bailey, J.H. and B.G. Witmer. 1994. “Learning and Transfer of Spatial Knowledge in a Virtual Environment.” In *Proc. Human Factors and Ergonomics Society 38th Annual Meeting*. 1158–1162.

Factors:	Training type (exploratory, restrictive), head-tracking (present, absent).
Computing platform:	SGI Crimson Reality Engine. Software Systems Multigen and Sense8 Corp. WorldToolKit.
Visual display:	Stereoscopic, color Virtual Reality Flight Helmet.
Tracking:	Head-tracking.
Navigation:	Using standard video game joystick.
Object manipulation:	None.
Virtual world:	Building.
Training:	None.
Experimental task:	3 rehearsals of circuitous route in VE using instructional strategy either based on finding and following successive landmarks (exploratory) or following left/right style directions (restrictive). Participants tested in actual building.
Participants:	64 participants; 32 males.
Study design:	Between-subjects.
Presence measures:	32-item Witmer-Singer PQ Version 2.0.
Person-related meas.:	Witmer-Singer 29-item ITQ Version 2.0.
Task-related measures:	Kennedy SSQ.
Performance measures:	Route knowledge: time taken to complete rehearsal, time spent in decision areas, time in stairways, number of collisions, time spent in collisions, time spent looking at landmarks, attempted number of attempted wrong turns, distance traveled, scores

on ordering route photographs. Building configuration knowledge: measured using paper-based and cathode ray tube (CRT)-based projection convergence technique for triangulating 4 targets from 3 sighting locations.

Findings:
(1) Training type and head-tracking each had no significant effect on presence.
(2) ITQ scores had a significant positive correlation with presence.
(3) Simulator sickness had a significant negative correlation with presence.
(4) Route knowledge only as assessed by photograph ordering test had a significant positive correlation with presence.
(5) Configuration knowledge only as assessed by accuracy on paper convergence test had a significant positive correlation with presence.
(6) Training type had a significant effect on route photograph ordering with exploratory condition leading to better results.
(7) Training type had a significant effect on time taken (using only participants who did not experience simulator sickness) and count of wrong turns, with restrictive condition taking less time but making more wrong turns.
(8) Head-tracking had a significant interaction with training type, such that restricted participants learned the configuration best without head-tracking, also a significant effect on rate of learning showing less time.
(9) Rehearsal trial had a significant negative effect on time spent in decision areas, time to complete rehearsal, time in stairways, time spent looking at landmarks, number of attempted wrong turns.
(10) ITQ scores had no significant correlation with any performance measure.
(11) SSQ scores had a significant positive effect on route completion time and CRT-based projective convergence test, and a significant negative correlation with photo-ordering accuracy.

[Baños 2004] Baños, R.M., C. Botella, M. Alcañiz, V. Liaño, B. Guerrero, and B. Rey. 2004. "Immersion and Emotion: Their Impact on the Sense of Presence." *CyberPscyhology*, 7(6), 734–741.

Factors: Emotion (sadness, neutral), visual display (HMD, rear-projection screen, desktop).
Computing platform: PC-based computers with high-end graphics capability.
Visual display: 5th Dimension Model 800 HMD, 400 × 150 cm rear-projection video wall, 17-in. desktop monitor.
Tracking: Head-tracking using Intersense Intertrax2.
Navigation: Using joystick.
Object manipulation: Using joystick.
Virtual world: One virtual world consisted of a park scenario designed to induce a sense of sadness using Mood Induction Procedures with music, narratives, Velten self-statements, pictures, movies, and autobiographical recalls.
Training: Practice in a training virtual world.
Experimental task: Free exploration of park for 2 min., go to bandstand and order a disordered statement while getting involved in the contents of each sentence, then navigate around park for another 2 min. Go to cinema and watch movie, then produce an autobiographical recall.
Participants: 60 university participants; 23 males; age range 18 to 49; mean age 24.8 yr. No history of neurological disease, head injury, learning disability, mental disorders, or psychological disorders, and nonuse of medications for psychological or emotional problems, and scores lower than 18 in the Beck Depression Inventory.
Study design: Between-groups.
Presence measures: Independent Television Commission-Sense of Presence Inventory (ITC-SOPI), 29-item version of Reality Judgment and Presence Questionnaire (RJPQ).

Findings:
(1) Emotion had a significant effect on ITC-SOPI subscales for Engagement and Ecological Validity with participants in the sad virtual world reporting more presence.
(2) Emotion had a significant effect on RJPQ subscales for Reality Judgment and Emotional Engagement with participants in the sad virtual world reporting more

presence; and a significant effect on RJPQ Emotional Indifference subscale with participants in the neutral virtual world reporting more presence.

(3) Visual display had a significant effect on ITC-SOPI scores with HMD participants reporting significantly less presence than the rear-projection screen or desktop monitor.

(4) Visual display had a significant effect on RJPQ Quality/Realism and Interaction/Navigation subscales with rear-projection screen participants reporting more presence.

(5) An interaction effect for emotion and display type wad found for ITC-SOPI Engagement and Ecological Validity subscales, with those in the sad group reporting more presence.

[Barfield 1998] Barfield, W., K.M. Baird, and O.J. Bjorneseth. 1998. "Presence in Virtual Environments as a Function of Type of Input Device and Display Update Rate." *Displays*, 19(2), 91–98.

Factors:	Update rate (20, 15, 10 Hz), navigation (3 DOF joystick, 3 DOF SpaceBall).
Computing platform:	SGI Indigo Extreme R4400 graphics workstation. In-house software with objects designed using Lambertian-shaded, 4-sided polygons of different shapes and sizes. Gouraud shading and ambient light model.
Visual display:	GE-610 6 × 8 ft. rear-projection screen, stereoscopic viewing using Stereographics Corp. CrystalEyes shutter glasses. Imagery generated at 1280 × 512 pixel resolution, 70° FOV and geometric FOV (GFOV). Eyepoint elevation 110 cm. Subject seated.
Navigation:	Measurement Systems Inc. Model 544 3 DOF joystick or Spatial Systems SpaceBall Model 1003 3 DOF spaceball.
Object manipulation:	None.
Virtual world:	Virtual Stonehenge in a night setting. Menhirs constructed of 4- and 6-sided polygons of different sizes and shapes. Ground was green, sky navy blue with stars, Stonehenge edifices beige. Passive ambient night sounds.
Training:	Two 4-min. training sessions in Virtual Stonehenge.
Experimental task:	Navigate site and search for a rune inscribed on one side of a menhir. 12 trials. 2-min. time limit.
Participants:	8 participants; 5 males; mean age 30 yr.
Study design:	Within-subjects.
Presence measures:	18-item presence questionnaire, questions categorized as (1) presence, (2) engagement of senses in virtual world, (3) fidelity of interaction.
Findings:	(1) Update rate had a significant positive effect for 13-items on presence questionnaire, with more presence reported for 15 or 20 Hz that for 10 Hz.
	(2) Navigation device had no significant effect on presence.

[Barfield 1995] Barfield, W. and C. Hendrix. 1995. "The Effect of Update Rate on the Sense of Presence Within Virtual Environments." *Human Factors*, 1(1), 3–16.

Factors:	Update rate (25, 20, 15, 10, 5 Hz).
Computing platform:	SGI Indigo Extreme workstation. Objects Lambertian shaded, designed using 4-sided polygons of difference shapes and sizes.
Visual display:	GE-610 6 × 8 ft. rear-projection screen, stereoscopic viewing using Stereographics Corp. CrystalEyes shutter glasses. Imagery generated with 1280 × 512 pixel resolution, GFOV 50º. Eyepoint elevation 110 cm. Subject seated with 90º FOV of screen. Black curtain to isolate viewing area.
Tracking:	Polhemus 3Space Fastrak for head-tracking.
Navigation:	3 DOF flight stick located on table in front of participant.
Object manipulation:	None.
Virtual world:	Virtual Stonehenge (see Barfield 1998).

Training:		10 practice trials in the VE.
Experimental task:		Navigate site and search for a rune inscribed on a wall. 12 trials. 2-min. time limit.
Participants:		13 participants; 9 males; mean age 25.3 yr.
Study design:		Within-subjects.
Presence measures:		13-item Barfield's presence questionnaire, including overall rating question; questions categorized as (1) presence and (2) fidelity of interaction.
Findings:	(1)	Update rate had a significant positive effect on presence, with less reported presence for 5 and 10 Hz than for 20 and 25 Hz when considering overall presence rating and 3 other questions directly related to presence. No significant difference for presence items related to awareness of the real world or simulation speed.
	(2)	Fidelity of interaction had a significant positive correlation with presence.
	(3)	Update rate had a significant positive effect on fidelity of interaction for all items, with increased fidelity for 20 to 25 Hz compared with 5 Hz.

[Barfield 1993 (1)] Barfield, W. and S. Weghorst. 1993. "The Sense of Presence Within Virtual Environments: A Conceptual Framework." In G. Salvendy and M.J. Smith (Eds.), *Human-Computer Interaction: Software and Hardware Interfaces,* New York: Elsevier, 699–704.

Visual display:		VPL Research EyePhones.
Tracking:		Polhemus six dimensional (6-D) tracker for hand tracking.
Navigation:		VPL Research DataGlove.
Object manipulation:		None.
Virtual world:		Two virtual worlds: (1) Virtual Seattle; (2) 3 similarly complex environments differing in their use of a ground plane and other spatial landmarks and in the visibility and degree of abstractness of objects.
Experimental task:		Navigating through two virtual worlds.
Participants:		86 participants; age range 14–59.
Presence measures:		3 items of 24-item questionnaire.
Person-related meas.:		Age, introspection, comfort with computers.
Task-related measures:		Ratings of enjoyment, engagement, ease of navigation, display comfort, being lost, display color quality, image clarity, movement ease, orientation in VE.
Findings:	(1)	Enjoyment had a significant positive correlation with "Sense of being there," "Sense of inclusion in the virtual world," and "Sense of presence in the virtual world."
	(2)	Age had a significant negative correlation with "Sense of inclusion in the virtual world."
	(3)	(In order of decreasing strength) display comfort, comfort with computers, ease of navigation, being lost, overall enjoyment, display color quality, and ability to get around had a significant positive correlation with "Sense of being there."
	(4)	(In order of decreasing strength) overall enjoyment, overall comfort, introspection, ease of interaction, ease of navigation, and movement ease had a significant positive correlation with "Sense of inclusion."
	(5)	(In order of decreasing strength) orientation within the virtual world, being lost, engagement, color quality, image clarity, overall enjoyment, and ability to get around had a significant positive correlation with "Sense of presence."

[Barfield 1993 (2)] Barfield, W. and S. Weghorst. 1993. "The Sense of Presence Within Virtual Environments: A Conceptual Framework." In G. Salvendy and M.J. Smith (Eds.), *Human-Computer Interaction: Software and Hardware Interfaces,* New York: Elsevier, 699–704.

Visual display:	VPL EyePhones.
Tracking:	Polhemus 6-D tracker for hand tracking.
Navigation:	Joystick handle with embedded tracker.
Object manipulation:	None.

Virtual world:	Various simple VEs.
Experimental task:	Designing 3-D model and object dynamics for a VE, then navigating, exploring, and interacting with implemented VE.
Participants:	69 participants; age range 8 to 16; mean age 11.8 yr.
Presence measures:	2 items of 27-item questionnaire.
Task-related measures:	Enjoyment of camp, enjoyment of designing/building a virtual world.
Findings: (1)	Enjoyment of designing and building a virtual world had a significant positive correlation with "feeling part of the virtual world."
(2)	Enjoyment of the technology camp had a significant positive correlation with "feeling part of the virtual world."

[Basdogan 1998] Basdogan, C., C.-H. Ho, M.A. Srinivasan, and M. Slater. 1998. "An Experimental Study on the Role of Touch in Shared Virtual Environments." *ACM Transactions on Computer Human Interactions*, 7(4), 443–460.

Factors:	Haptic force feedback (present, absent).
Computing platform:	IBM compatible personal computer (PC) with dual Pentium II 300-MHz processors, 3-D graphics accelerator. Open Inventor rendering software for visual display, in-house software for haptic rendering.
Visual display:	Two monitors.
Haptic display:	Two SensAble Technologies, Inc. PHANTOM devices each providing force feedback to a single finger; haptic update rate 1 kHz.
Object manipulation:	PHANTOMs slaved to ring with each contact point represented by a cursor positioned on the ring. Both partners press on the ring at the same time to hold it and move it.
Virtual world:	World consisted of bent wire strung between two end points. Ring positioned loosely over wire with blue/green cursors to denote participants' contact points. Background of two walls positioned to form a back wall and floor. Wire and ring cast a shadow on the floor.
Experimental task:	Work with a remote partner (the same expert user expected to exhibit constant performance across trials) to move a ring back and forth along a wire while minimizing or avoiding contact between the wire and the ring. Contact between wire and ring denoted by ring color and surrounding walls changing color.
Participants:	10 participants.
Study design:	Within-subjects.
Presence measures:	8-item Co-presence Questionnaire.
Person-related meas.:	Social anxiety, age, gender, computer use.
Task-related measures:	Social anxiety assessment of partner.
Performance measures:	Proportion of time ring was not intersecting the wire.
Findings: (1)	Haptic force feedback had a significant positive effect on co-presence.
(2)	Gender had a significant effect on co-presence, with females reporting higher co-presence.
(3)	Age had a significant negative correlation with co-presence.
(4)	Computer use had a significant positive correlation with co-presence.
(5)	Participant's social anxiety had a significant relationship with co-presence, negative for males, positive for females.
(6)	Extent of social anxiety of partner had a significant positive correlation with co-presence.
(7)	Task performance had a significant positive correlation with co-presence for the haptic force feedback condition only.
(8)	*Haptic feedback had a significant positive effect on performance.*
(9)	*Group had a significant interaction with condition, such that use of the visual system only first, followed by the visual and haptic system, resulted in better performance than the reverse order.*

[Biocca 2001] Biocca, F., J. Kim, and Y. Choi. 2001. "Visual Touch in Virtual Environments: An Exploratory Study of Presence, Multimodal Interfaces, and Cross-Modal Sensory Illusions." *Presence*, 10(3), 247–265.

Computing platform:	SGI Onyx Reality Engine with 2 graphics pipes. Software Systems Multigen Smart Scene software.
Visual display:	Stereoscopic Virtual Research V8 HMD.
Tracking:	Polhemus magnetic tracking for head and hands.
Object manipulation:	Fakespace Labs Pinch gloves for using gestures to grab and move objects. A visual representation of a spring indicated that an object was being pulled away from its "snap" position. When pulled far enough, the spring was retracted and the object "popped" into participant's hand.
Virtual world:	Environment 1: Media Interface and Network Design (M.I.N.D.) Lab's Virtual Hands-on Cadaver Environment; 3-D room resembling a doctor's examining room, with examining table and a cadaver (realistic skeleton with 8 complete organs in rib cage) and medical charts on the wall. Environment 2: Similar to first environment but with a collection of simple symmetrical polygonal shapes occupying the same space and location of the cadaver, matching the number of objects in the virtual cadaver. Hands represented as 3-D cursors (blue transparent sphere with embedded tubular cross).
Training:	View recorded training session to provide basic instructions in how to navigate the environment and manipulate objects. Participants spent time in a training VE (an open city space) until they felt comfortable with that environment.
Experimental task:	In the experimental environment: remove all organs from the cadaver. In the control environment, remove symmetrical objects.
Participants:	77 university students.
Presence measures:	Questionnaire.
Task-related measures:	Cross-modal visual-to-haptic and visual-to-aural illusions.
Findings: (1)	Reports of cross-modal visual-to-haptic illusions had a significant positive correlation with presence.
(2)	Reports of cross-modal visual-to-aural illusions had no significant correlation with presence.

[Botella 1999] Botella, C., A. Rey, C. Perpiñá, R. Baños, M. Alcañiz, A. Garcia-Palacios, H. Villa, and J. Alozano. 1999. "Differences on Presence and Reality Judgment Using a High Impact Workstation and a PC Workstation." *CyberPsychology & Behavior*, 2(1), 49–52.

Factors:	Level of equipment (SGI with FS5 HMD and 3-D joystick, Pentium II with Virtual Research V6 HMD and 2-D mouse).
Computing platform:	SGI high impact computer graphics workstation with Division, Ltd. dVISE software or Pentium II-based workstation with AccelEclipse Graphical Card with Sense8 Corp. WorldUp software.
Visual display:	High-quality Virtual Research FS5 HMD or medium-quality V6 HMD.
Navigation:	Using a Division, Ltd. 3-D joystick or standard 2-D mouse.
Virtual world:	Designed for treatment of claustrophobia, consisting of a room where participants could walk and open/close windows and doors, and a second smaller room where participants could walk and open/close the door and move one of the walls to narrow room dimensions.
Experimental task:	15-min. exposure.
Participants:	69 undergraduates; age range 19 to 35.
Study design:	Between-subjects.
Presence measures:	15-item RJPQ.
Findings: (1)	Level of equipment had no significant effect on presence or reality judgment.

[Bouchard 2004] Bouchard, S., J. St.-Jacques, and P. Renaud. March 2004. "Anxiety Increases the Feeling of Presence in Virtual Reality." *Presence-Connect*, 4.

Factors:	Type of virtual world (neutral/control environment, desert-like environment without induced anxiety).
Computing platform:	PC with ATI Radion graphic card.
Visual display:	I-O Display Systems I-Glass HMD, with 640 × 480 resolution, 26º diagonal FOV.
Tracking:	Head-tracking using an InterSense Intertrax 3 DOF tracker.
Navigation:	Microsoft joystick.
Object manipulation:	None.
Virtual world:	The neutral/control virtual world was based on a modified version of the Assault-Mazon map of the 3-D game Unreal Tournament – Game of the Year Edition®. The desert-like environment mirrored snakes' natural habitat and was based on a modified version of the map "The Temple of Horus" from the game Unreal Tournament – Game of the Year Edition®.
Training:	During exploration of the neutral/control world.
Experimental task:	Explore the neutral/control virtual world. Then explore the second virtual world, once when told no snakes were present and once when told that poisonous, aggressive, and dangerous snakes were hidden and lurking in it. Participants performed a reading-based distraction task between the last two sessions. 5-min. exposure to each virtual world.
Participants:	31 participants; 5 males; age range 27 to 68. Suffered from a specific phobia of snakes but did not suffer from major depression, psychotic disorders, or any other mental disorder that would require immediate treatment and were not taking drugs or substances that would block the effect of anxiety. Had no prior experience with VE systems.
Study design:	Within-subjects.
Presence measures:	Presence questionnaire, verbal rating of presence halfway through and at end of each session.
Person-related meas.:	State-Trait Anxiety Inventory.
Performance-related measures:	Verbal rating of anxiety halfway through and at end of each session.
Findings: (1)	Type of virtual world had a significant effect on the verbal rating of presence with increased presence reported for the anxiety-inducing virtual world than for the neutral/control world.
(2)	Type of virtual world had a significant effect on PQ scores, with less presence reported for the anxiety-inducing virtual world.
(3)	The verbal rating of presence had a significant correlation with PQ Total scores at the mid-point and end of the session in the controlled environment.
(4)	Anxiety had a significant positive correlation with the mid-point and final rating of presence for each of the last two sessions. The correlations between change scores in anxiety and presence from the second to the third immersion also were significant for the mid-point and final presence ratings.
(5)	*Type of virtual world had a significant effect on anxiety, with more anxiety reported for the anxiety-inducing virtual world than for the neutral/control world.*
(6)	*Type of virtual world had no significant effect on SSQ scores.*

[Brogni 2003] Brogni, A., M. Slater, and A. Steed. 2003. "More Breaks Less Presence." Presented at the 6th Annual International Workshop on Presence. 6–8 October, Aalborg, Denmark.

Visual display:	Trimension ReaCTor with 4 walls.
Tracking:	Using Intersense system.
Navigation:	Using a wand.

Object manipulation:	None.
Virtual world:	Urban environment.
Training:	Training in recognition of breaks in presence (BIPs) through visualization of Gestalt 2-D images.
Experimental task:	Experience urban environment, pressing a button on the wand to indicate a BIP. 4–5 min.
Presence measures:	Count of BIPs, 4-item Slater-Usoh-Steed (SUS) Questionnaire.
Task-related measures:	4-item Consistency Check Questionnaire.
Findings: (1)	Count of BIPs had a significant negative correlation with reported presence.
(2)	3 of 4 items on the Consistency Check Questionnaire had a significant correlation with reported presence in the expected direction.

[Brown 2003] Brown, S., I. Ladeira, C. Winterbottom, and E. Blake. 2003. "An Investigation on the Effects of Mediation in a Storytelling Virtual Environment." In *Proceedings 2nd International Conference on Virtual Storytelling*, 20–21 November, Toulouse, France.

Factors:	Mediation (visual and audio, visual, audio, none).
Computing platform:	Two PCs, with frame rate 10 to 20 fps. Genesis3-D engine.
Visual display:	19-in. monitors.
Audio display:	Headphones.
Tracking:	None.
Navigation:	Mouse (for pitch and yaw), keyboard (for movement, sitting, and standing).
Object manipulation:	None.
Virtual world:	Cave at night time, where cave is situated on rough, barren terrain with digital photographs of the Cederberg mountains used to texture rocks. Interior of cave includes a fire surrounded by 3 figures. Sound partially spatialized to provide direction and location. Visual mediation consisted of San rock paintings; audio mediation was sounds of fire cracklings and crickets chirping.
Experimental task:	Approach the group around the fire. Listen to welcome from storyteller, then sit and listen to story with other San hunters.
Training:	Practice in virtual Familiarity Room.
Participants:	77 first- and second-year Economics and Psychology students.
Study design:	Between-subjects.
Presence measures:	Igroup Presence Questionnaire (IPQ).
Task-related measures:	*Rating of involvement in story, rating of enjoyment in virtual world.*
Findings: (1)	Visual mediation had no significant effect on presence.
(2)	Audio mediation had a significant effect on presence, with more presence reported for use of environmental night sounds.
(3)	Enjoyment and involvement each had a significant positive correlation with presence.
(4)	*Enjoyment and mediation had a significant interaction, with visual mediation affecting enjoyment only when audio mediation was present, and vice versa.*
(5)	*Visual mediation only had a significant effect on involvement.*

[Bystrom 1999] Bystrom, K.-E. and W. Barfield. 1999. "Collaborative Task Performance for Learning Using a Virtual Environment." *Presence*, 8(4), 435–448.

Factors:	Collaboration (single user, pair), navigation (control of movement and navigation, control of movement only, control of navigation only, no control), head-tracking (present, absent).
Computing platform:	SGI Indigo Extreme workstation. In-house software.
Visual display:	GE 610 6 × 8 ft. rear-projection screen. Images displayed using Stereographics Corp. CrystalEyes shutter glasses with 1280 × 512 pixel resolution. Update rate

	6 fps. Participants seated in front of projection screen so that their position subtended a 90° FOV with the display screen.
Tracking:	Polhemus 3Space Fastrak for head-tracking.
Navigation:	Standard mouse controlled by participant with head-tracking, located on small table in front of participant. Participant who "controlled" navigation operated mouse or gave instructions to mouse controller.
Object manipulation:	None.
Virtual world:	Virtual room with objects such as tables, chairs, a desk, a bookshelf, a telephone, and a notepad. 6 versions of the room formed by relocating certain objects.
Experimental task:	Navigate through a virtual room and identify objects moved from position given on a provided diagram. Took diagram of room showing initial object locations into VE, along with additional diagram onto which marked changes of location. 2 treatments alone, 4 working with a partner. Each trial 3 min.
Participants:	20 participants recruited from university engineering classes, and software companies or associations; 10 males; age range 16 to 49; mean age 28 yr. 9 participants had previous VE experience, 4 of these had over 20-min. experience. 8 pairs of participants knew each other prior to the study.
Study design:	Within-subjects.
Presence measures:	11-item presence questionnaire, 6 items answered by all participants, remaining questions depending on condition.
Performance measure:	*Number objects correctly identified, with movement also correctly identified.*
Findings: (1)	Collaboration had no significant effect on presence, although those who worked with a known partner reported significantly more presence than those who worked with a stranger.
(2)	Navigation had no significant effect on presence.
(3)	Head-tracking had a significant positive effect on presence for only 1 question ("How realistically did the virtual world move in response to your head motions?").
(4)	*Collaboration had a significant positive effect on task performance.*
(5)	*Navigation had a significant positive effect on task performance, with better performance found for those working alone who had more control or who worked with a partner than for those working alone with no control.*
(6)	*Head-tracking had no significant effect on task performance. When considering collaboration, head-tracking did have a significant positive effect, with better performance found for participants with head-tracking and whose partner had head-tracking than for participants working alone with no head-tracking.*

[Bystrom 1996] Bystrom, K.-E. and W. Barfield. 1996. "Effects of Participant Movement Affordance on Presence and Performance in Virtual Environments." *Virtual Reality*, 2(2), 206–216.

Factors:	Movement (seated with chin rest, seated without chin rest, standing).
Computing platform:	SGI Indigo Extreme workstation. In-house software.
Visual display:	GE 610 6 × 8 ft. rear-projection screen. Images displayed using Stereographics Corp. CrystalEyes shutter glasses with 1280 × 512 pixel resolution. Update rate 9 fps. Participants positioned initially so their position subtended a 90° FOV with the projection screen.
Tracking:	Polhemus 3Space Fastrak for head-tracking.
Navigation:	Standard mouse attached to a clipboard either handheld, or for chin rest condition placed on table in front of participant.
Object manipulation:	None.
Virtual world:	Virtual cabin with furniture including tables, chairs, a desk, a bookcase, windows with outside scenes, and cupboards. 7 target (A-M) letters positioned around room, mixed with 6 distractor (N-Z) letters. Different versions of room prepared by moving letters: 3 versions for practice trials, 3 versions for experimental trials.
Experimental task:	Locate the target letters. No time limit, focus on accuracy rather than speed.

Participants: 11 participants from university engineering classes and local software community; 7 males; age range 21 to 9; mean age 25 yr. 6 had previous VE experience, 5 of these had more than 20-min. experience.

Study design: Within-subjects.

Presence measures: 11-item questionnaire, with overall presence rating.

Person-related meas.: Age.

Task-related measures: Rating of task difficulty, rating of enjoyment.

Performance measure: Search time.

Findings:

(1) Movement had no significant effect on the rating of presence.

(2) *Movement had no significant effect on ratings of realism of depth/volume, ability to reach into VE, task difficulty, or enjoyment. There was a significant effect for head movement realism, with more realism reported by participants who stood or sat.*

(3) Presence had a significant positive effect on search time only for participants who reported their sense of presence increased when seated.

(4) Presence had no significant correlation with age, a significant positive correlation with response realism, realism of depth/volume, and a significant negative correlation with reports that presence was affected by standing.

(5) Movement had no significant effect on task performance. There was a significant interaction between task complexity and gender, such that males performed better in the more complex task, whereas females faired better in the simple task.

(6) Task performance had a significant positive correlation with task difficulty and reports that presence was affected by sitting but had no significant correlation with age, response realism, depth/volume realism, ability to reach into VE, or enjoyment.

[Casanueva 2001 (1)] Casanueva, J. April 2001. *Presence and Co-Presence in Collaborative Virtual Environments*. M.Sc. Dissertation. University of Cape Town, South Africa.

Factors: Collaboration (group members had to collaborate to unlock padlocks attached to shapes, no collaboration required).

Computing platform: SGI Onyx RealityEngine2 with four 200-MHz R4400, 128 MB RAM. SGI O2 with a 175-MHz R10000 processor, 128 MB RAM. SGI O2 with a 195-MHz R10000 processor, 256 MB RAM. Distributed Interactive Virtual Environment (DIVE) software developed by the Swedish Institute of Computer Science, supporting avatar gravity and collision detection, and University College London (UCL) Robust Audio Tool (RAT) audio software.

Visual display: Two 21-in. monitors, one 17-in. monitor.

Audio display: Headphones.

Navigation: Using keyboard arrow keys.

Object manipulation: Pick up and move objects by clicking and releasing mouse button.

Virtual world: Set of rooms with textured walls, floors, and ceiling that formed a virtual maze. Participants represented by simple “T”-shaped avatars, each participant with a different color (Red, Blue, Green). Participants could not see their own avatar. Audio communications between participants in a group using microphones and headphones.

Training: Familiarization with VE, including learning how to move through the environment and how to pick up objects.

Experimental task: Move pyramids, cubes, and rectangles into the room marked for each type of shape. Shapes colored to match avatars and could be picked up only by an avatar of the same color. In high-collaboration condition, each shape has an attached padlock of different color, requiring 2 members to collaborate with one clicking to unlock padlock and another to pick up shape within 6 seconds. No padlocks were used in the low-collaboration condition. 25-min. time limit.

Participants: 10 groups of 3 students from second-year psychology course.

Study design: Between-groups.

Presence measures: 5-item SUS Questionnaire, Co-presence Questionnaire.
Person-related meas.: 19-item Witmer-Singer ITQ.
Task-related measures: 14-item Collaboration and Group Accord questionnaire.
Findings:
(1) Collaboration had a significant positive effect on presence, co-presence, and collaboration score.
(2) Co-presence had no significant correlation with presence.
(3) Collaboration score had a significant correlation with co-presence, a positive correlation in the high-collaboration condition and a negative correlation in the low-collaboration condition. Collaboration score had no significant correlation with presence.
(4) ITQ score had a significant positive correlation with presence but had a significant positive correlation with co-presence only when group collaboration was required for task performance.
(5) Collaboration had a significant positive effect on collaboration score.

[Casanueva 2001 (2)] Casanueva, J. April 2001. *Presence and Co-Presence in Collaborative Virtual Environments*. M.Sc. Dissertation. University of Cape Town, South Africa.

Factors: Presence manipulation (high presence, low presence).
Computing platform: SGI Onyx ReaityEngine2 with 128 MB RAM. SGI O2 with a R10000 processor, 256 MB RAM. SGI O2 with a R10000 processor, 128 MB RAM. DIVE and RAT software. SGI Indy for recording dialogue in high-presence environment.
Visual display: Two 21-in. monitors, one 17-in. monitor.
Audio display: Headphones (and microphones) in high-presence condition.
Navigation: Using keyboard arrow keys.
Object manipulation: Pick up and move objects by clicking and releasing button on 3-button SGI mouse.
Virtual world: 10 rooms in an open plan office layout each with a word printed on either the wall (high-presence) or floor (low-presence). Each word with missing letters. These letters scattered in the form of 10 cubes that had the letter written on all sides. Self-representation as colored avatars.
Training: Practice session in the VE, where participants learned how to move through the environment, communicate with each other, and pick-up and drop objects.
Experimental task: Pick up and move cubes to place correct missing letter by each word. Letters could be used in more than 1 word. In low-presence condition, experimenter interrupted participant asking about and then bringing a soft drink. 25-min. time limit.
Participants: 6 groups of 3 students and 1 group of 2 students; 9 males.
Study design: Between-groups.
Presence measures: 34-item Witmer-Singer PQ, Co-presence Questionnaire, total presence (weighted sum of presence and co-presence scores).
Person-related meas.: 19-item Witmer-Singer ITQ.
Findings:
(1) Presence manipulation had a significant effect on co-presence, and total presence, with increased presence reported for the high presence environment but had no significant effect on presence.
(2) Co-presence had no significant correlation with presence.
(3) Co-presence and total presence scores had no significant correlation with ITQ scores. Presence had a significant positive relationship with ITQ scores in the high presence environment only.
(4) Presence manipulation had no significant effect on ITQ scores.

[Casanueva 2001 (3)] Casanueva, J. April 2001. *Presence and Co-Presence in Collaborative Virtual Environments*. M.Sc. Dissertation. University of Cape Town, South Africa.

Factors:		Avatar realism (realistic human-like, cartoon-like, unrealistic).
Computing platform:		SGI Onyx RealityEngine2 with four 200-MHz R4400 processors, 128 MB RAM. SGI O2 with a 175-MHz R10000 processor, 128 MB RAM. SGI O2 with a 195-MHz R10000 processor, 256 MB RAM. DIVE and RAT software.
Visual display:		Two 21-in. monitors, one 17-in. monitor.
Audio display:		Headphones (and microphones).
Navigation:		Using keyboard arrow keys.
Object manipulation:		Pick up and move objects by clicking and releasing mouse button.
Virtual world:		Conference room where multiple users meet around a table and have a discussion. Each participant had a book on the table that could be used to view a document. Whiteboard on one wall. Fully textured. Participants could not see their own avatar. Avatars of others had no gestures or facial expressions.
Training:		Learning how to move through the environment and pick up objects.
Experimental task:		Read a short story by accessing the book on the virtual table and agree on a ranking for the 5 characters in the story, using a grid display and markers on the white board to aid the discussion. 20-min. time limit.
Participants:		6 groups of 3 students from second-year psychology course.
Study design:		Between-groups.
Presence measures:		5-item SUS Questionnaire, Co-Presence Questionnaire.
Person-related meas.:		19-item Witmer-Singer ITQ.
Findings:	(1)	Avatar realism had a significant effect on co-presence, with participants seeing realistic avatars reporting more presence than those seeing unrealistic avatars.
	(2)	Co-presence had no significant correlation with presence.
	(3)	ITQ score had a significant positive correlation with presence, but no significant relationship with co-presence.

[Casanueva 2001 (4)] Casanueva, J. April 2001. *Presence and Co-Presence in Collaborative Virtual Environments*. M.Sc. Dissertation. University of Cape Town, South Africa.

Factors:		Avatar functionality (gestures, gestures and facial expressions, no functionality).
Computing platform:		Experimental task: As in [Casanueva 2001 (3)] except avatars had gestures (waving, raising arms, joy and sad gestures, head movements such as yes, no, and perhaps, walking) and facial expressions (sad, happy, neutral, surprised, disgusted, angry, furious).
Participants:		10 groups of 3 students from second-year psychology course.
Study design:		Between-groups.
Presence measures:		5-item SUS Questionnaire, Co-Presence Questionnaire.
Person-related meas.:		19-item Witmer-Singer ITQ.
Findings:	(1)	Avatar functionality had a significant effect on co-presence, with those seeing avatars with gestures and facial expression reporting more co-presence than those seeing avatars with no functionality.
	(2)	Co-presence had no significant correlation with presence.
	(3)	ITQ score had a significant positive correlation with presence but had no significant relationship with co-presence.

[Chapman 2003] Chapman, K., J. Freeman, E. Keogh, C. Dillon, M. Jorquera, B. Rey, R. Baños, and M.A. Raya. 2003. "Investigating the Relationship Between Presence and Emotion Using Virtual Mood Induction Procedures." Presented at Presence 2003.

Visual display:		Projection screen 127 × 94 cm, with viewing distance to provide FOV 24°H × 18°V.
Tracking:		None.
Navigation:		None.
Object manipulation:		None.
Virtual world:		Different versions of a park containing a pagoda, statue, water pool, cinema, and trees. Variations include time of day, and weather associations with mood.
Experimental task:		View a fly-through of one version of a sad, happy, anxious, relaxed, or neutral version of the park.
Participants:		127 students.
Study design:		Within-subject.
Presence measures:		ITC-SOPI, *SUS Questionnaire*.
Person-related meas.:		Visual Analogue Scale (VAS), Positive Affect Negative Affect Schedule (PANAS).
Findings:	(1)	VAS scores had a significant correlation with ITC-SOPI scores (only examined for the sad and anxious versions of the park).
	(2)	PANAS scores had a significant correlation with ITC-SOPI scores (only examined for the sad and anxious versions of the park).
	(3)	*Viewing the park had a significant effect on VAS and PANAS scores for the sad and anxious versions of the park.*

[Cheung 2002] Cheung, P. and P. Marsden. 2002. "Designing Auditory Spaces to Support Sense of Place: The Role of Expectation." In *Proc. CSCW 2002,* 16–20 November, New Orleans, LA.

Factors:		Stimuli (matching, mismatching).
Computing platform:		Pentium PC. Replay using Macromedia Director. Physiological data collection using Datalab 2000 with Biobench software.
Visual display:		Projection screen, resolution 800 × 600.
Audio display:		Binaural sound recordings played over Sennheiser eH2270 headphones.
Tracking:		None.
Audio sequences:		Sounds clips of 60-sec. length recorded from a pub, supermarket, higher street, and train station.
Visual stills:		Matching audio sequences.
Training:		Listen to recoding and view image of a park.
Experimental task:		Listen to audio while viewing still image. 4 trials. Approx. 20 min.
Participants:		20 students and university staff.
Study design:		Between-subjects.
Presence measures:		9-item version of the Swedish Viewer-User Presence (SVUP).
Task-related measures:		*Δskin conductance, Δblood pressure*.
Performance measures:		*Memory test of place-related questions*.
Findings:	(1)	Stimuli had a significant effect on presence, with more presence reported for matching audio-visual stimuli.
	(2)	*Stimuli had no significant effect on task performance.*
	(3)	*Stimuli had no significant effect on skin conductance or blood pressure*.

[Cho 2003] Cho, D., J. Park, G.J. Kim, S. Hong, S. Han, and S. Lee. 2003. "The Dichotomy of Presence Elements: The Where and How." In *Proc. IEEE Conference on Virtual Reality, VR'03*.

Factors:		Stereoscopy (present, absent), user motion (fixed navigation, none), object motion (moving fish, stationary fish), object self motion (with deformation, no deformation), geometry (high polygon count, low polygon count), texture (present, absent).
Visual display:		50-in. screen.
Audio display:		None.
Tracking:		None.
Navigation:		Either fixed or none.
Object manipulation:		None.
Virtual world:		Simple undersea world with rocks and fish.
Experimental task:		View 32 versions of virtual world for 90 sec. each.
Presence measures:		4-item Realism and Presence Questionnaire.
Task-related measures:		*Ranking of importance of 5 visual elements for creating a sense of being in the undersea world.*
Findings:	(1)	Stereoscopy, geometry, and texture each had a significant effect on presence.
	(2)	User motion had a significant effect on presence, also a significant interaction with texture.
	(3)	Object motion had a significant effect on presence, also a significant interaction with geometry and texture.
	(4)	Object self-motion had no significant effect on presence.
	(5)	*Stereoscopy, object motion, and user motion had a significant effect on realism.*
	(6)	*Geometry had a significant effect on realism, also a significant interaction with object motion.*
	(7)	*Texture had a significant effect on realism, also a significant interaction with object motion and user motion.*
	(8)	*Object self-motion had no significant effect on realism.*

[Choi 2001] Choi, Y.K., G.E. Miracle, and F. Biocca. 2001. "The Effects of Anthropomorphic Agents on Advertising Effectiveness and the Mediating Role of Presence." *Journal of Interactive Advertising*, 2(1).

Factors:		Avatar use (advertising avatar, no avatar).
Computing platform:		Developed using 3-D Studio Max, Character Studio, and Macromedia Director 7.
Visual display:		Desktop monitor.
Web site:		Designed to market t-shirts and socks under a fictitious brand name. Included a welcome message for customers, information search options, purchase instructions, and farewell message in a 3-D background setting. The version with an agent presented messages using the agent voices and nonverbal cues such as head nodding, waving hands, and moving arms. The same message was provided in textual format in the other version.
Experimental task:		Navigate to Web site and then examine site.
Participants:		207 undergraduate students from introductory advertising classes.
Study design:		Between-subjects.
Presence measures:		10-item presence questionnaire, 6-item Social Presence Questionnaire.
Task-related measures:		*Attitude toward the advertisement, attitude toward brand, intention to purchase, intention to revisit Web site scales (used as measures of advertising effectiveness).*
Findings:	(1)	Avatar use had a significant effect on presence, with more presence reported when the avatar was used.
	(2)	Avatar use had a significant effect on social presence, with more presence reported when the avatar was used.
	(3)	Presence had a significant positive correlation with social presence.

(4) Presence and social presence had a significant positive relationship with intention to revisit the Web site, and various mediating relationships with advertising effectiveness were found.

(5) Avatar use had a significant effect on attitudes toward the advertisement and intention to revisit the Web site, with avatar use resulting in more positive attitudes and intentions. It had no significant effect on attitude toward brand or intention to purchase.

[Commarford 2001] Commarford, P.M., M.J. Singer, and J.P. King. 2001. *Presence in Distributed Virtual Environments*. U.S. Army Research Institute for the Behavioral and Social Sciences. Orlando, FL.

Computing platform:	SGI Onyx and RealityEngine2 with eight 200-MHz, 256-MB RAM R4400 processors. In-house software.
Visual display:	Stereoscopic, color Virtual Reality VR8 HMDs.
Audio display:	Stereo headphones.
Tracking:	Head, each ankle, right wrist and elbow, and harness sensors tracked by an Ascension Technologies MotionStar (wired version) with an extended range transmitter.
Navigation:	Walking-in-place on a platform with barrier.
Virtual world:	Several scenarios using 10-room virtual buildings laid out along a single corridor approximately 4 meters wide with one 90º turn, either to the right or left. Corridors all scaled to 70 m in length, with the turn at 20, 25, or 30 m. Rooms varied between 5 × 10 m and 15 × 10 m in size, with office furniture, home furnishings, warehouse shelving, bookcases, and desks placed in realistic arrangements. The buildings were designed to represent normal offices, a school, a department store, a library, a warehouse, and single story homes. The scenarios ranged from simple to complex with varying numbers of neutral hostages, opposing forces, and gas canisters. Canisters had 1 or 3 possible states: no gas and not armed, gas and not armed, gas and armed. Sound cues included voice communications, collision noises, door opening, grenade explosions, and gunfire.
Training:	Individual and teamed with an automated partner for 4-hr. training session on VE equipment and tasks, in which exposed to VE 3 to 4 times. Started with walking through a simple VE; final training included equipment operation and team tasks partnered with an automated agent.
Experimental task:	Paired with partner to complete a series of 8 VE mission rehearsals. Each mission involved searching for and disarming gas canisters.
Participants:	64 students.
Person-related meas.:	29-item ITQ Version 2.0.
Presence measure:	Winter-Singer PQ.
Findings:	(1) PQ scores taken after final training were significantly different from PQ scores after initial, simple movement training for PQ Total, PQ Natural, Involved/Control, Auditory, and Haptics subscales, with higher presence reported after final training.
	(2) PQ scores taken after the first team mission were significantly different from PQ scores after final training for PQ Total and PQ Involved/Control subscale, with higher presence reported after final training.
	(3) PQ scores taken after the last team mission were significantly different from PQ scores after the first mission for PQ Total and PQ Involved/Control subscale, with increased presence reported after the final mission.
	(4) When measured after initial training, ITQ Focus subscale had a significant positive correlation with PQ Total, and PQ Involved/Control and PQ Resolution subscales.
	(5) When measured after final training, ITQ scores had no significant correlation with PQ scores.

[Darken 1999 (2)] Darken, R.P., D. Bernatovich, J.P. Lawson, and B. Peterson. 1999. "Quantitative Measures of Presence in Virtual Environments: The Roles of Attention and Spatial Comprehension." *CyberPsychology & Behavior*, 2(4), 337–347.

Factors:	Audio cues (semantic and spatial information, semantic information, spatial information, no cues).
Visual display:	3-screen semi-circular mini-Cave.
Navigation:	Joystick for viewpoint control only.
Object manipulation:	None.
Virtual world:	Participant given a guided car tour of a town. Semantic audio cues provided information such as "This Mobil Station has a car wash and was built 3 years ago"; spatial audio cues provided information such as "This Mobil Station is on the north side of town adjacent to the park."
Experimental task:	Observe the virtual world while on an automated car tour.
Participants:	40 participants; 33 males; mean age 32.5 yr.
Study design:	Between-subjects.
Presence measures:	32-item Witmer-Singer PQ Version 2.0.
Performance measures:	Spatial knowledge acquisition: map building and pointing task scores, number correct landmarks selected.
Findings: (1)	Audio cues had a significant positive effect on PQ scores, with both semantic and spatial information cues yielding more presence than no audio cues.
(2)	Map building and landmark identification scores had no significant correlation with PQ scores.
(3)	*Audio cues had no significant effect on map building scores or pointing task scores but had a significant effect on landmark selection, with both the spatial and spatial with semantics cues giving better performance.*

[Dinh 1999] Dinh, H.Q., N. Walker, L.F Hodges, C. Song, and A. Kobayashi. 1999. "Evaluating the Importance of Multi-sensory Input on Memory and the Sense of Presence in Virtual Environments." In *Proc. IEEE Virtual Reality Conference*, 13–17 March, Houston, TX. 222–228.

Factors:	Tactile cues (present, absent), olfactory cues (present, absent), audio cues (present, absent), visual detail (high detail, low detail).
Computing platform:	Modeled using Alias Wavefront. Rendered by in-house software built using Georgia Institute of Technology's Simple Virtual Environment (SVE) toolkit.
Visual display:	HMD with frame rate 20 fps.
Tactile display:	Tactile cues, when present, were a real fan to produce effect of virtual fan and heat lamp used to simulate standing in sunshine.
Olfactory display:	Olfactory cue was the scent of coffee delivered using a small oxygen mask connected to (1) a canister of coffee grounds and a small pump and (2) a fresh air source and additional pump.
Auditory display:	Delivered via headphones: sound of a fan, a toilet flushing, a copier machine, and city noise; volumes (usually On/Off) varied according to participant's location.
Tracking:	Head-tracking.
Navigation:	None, participant positioned at 2 locations within each room in the VE.
Object manipulation:	None.
Virtual world:	Corporate office suite including a reception area, hallway, bathroom, small office, copier room, larger office, and balcony. All spaces appropriately furnished. Texture mapping for pictures, furniture material, and an outdoor city view. For high visual detail, local light sources were simulated and high-resolution text maps used; for low visual detail used only ambient lighting and reduced texture resolutions to 25% previous value.

Training:	Training room containing objects such as books on the floor, a table, a vase, and a speaker. Training task to find each of 5 specific objectives.
Experimental task:	Evaluate the effectiveness of a VE system for use by real estate brokers. Virtual tour took approximately 5 min.
Participants:	322 undergraduate students. At most, 1 had previous experience in a VE.
Study design:	Between-subjects.
Presence measures:	14-item questionnaire, including an overall rating of presence.
Performance measures:	*Memory test with 4 items on Spatial Layout Questionnaire, 5 items on object location.*
Findings: (1)	Audio cues and tactile cues had a significant positive effect on presence.
(2)	Visual detail and olfactory cues had no significant effect on presence.
(3)	*Audio, tactile, visual, and olfactory cues had no significant effect on spatial layout memory. Tactile and olfactory cues had a significant positive effect on object location memory; audio and visual cues had no significant effect.*

[Freeman 2004] Freeman, J., J. Lessiter, E. Keogh, F.W. Bond, and K. Chapman. 2004. "Relaxation Island: Virtual, and Really Relaxing." In *Proc. 7th Annual International Workshop: Presence 2004*. 13–15 October, Valencia, Spain: Universidad Politecnica de Valencia.

Factors:	Virtual world (present, absent).
Visual display:	Projection screen.
Navigation:	Using keyboard.
Object manipulation:	None.
Virtual world:	Island with several zones (waterfall, beach 1, beach 2, cloud), each developed to facilitate the delivery of instructions intended to modify negative thinking and anxious mood state. Island supported with imagery that might facilitate relaxation and acceptance, such as calming sea waves and sounds of a tropical island. When provided, virtual world supported a therapeutic narrative.
Training:	None.
Experimental task:	Listen to therapeutic narrative with eyes close while experimenter navigated to a beach on relaxation island or listen to therapeutic narrative and simultaneously navigate self to the beach. Participant seated. Duration 7 min. 20 sec.
Participants:	20 students and university staff; 10 males; age range 20 to 56; mean age 30.2 yr. Screening based on Acceptance and Action Questionnaire, General Health Questionnaire, Depression Anxiety Stress Scale.
Study design:	Between-groups.
Presence measures:	44-item ITC-SOPI, *3-item UCL Presence Questionnaire*.
Person-related meas.:	PANAS emotion scale and VAS emotion scale, *Short Bett's Questionnaire on Mental Imagery*.
Findings: (1)	Use of the virtual world had a significant effect on ITC-SOPI scores, with increased presence reported for the Sense of Physical Space, Engagement, Ecological Validity, and Negative Effects subscales.
(2)	ITC-SOPI subscales Sense of Physical Space, Engagement, Ecological Validity each had a significant positive correlation with changes in VAS happiness.
(3)	ITC-SOPI Engagement had a significant positive correlation with PANAS Negative Affect changes.
(4)	*Use of the virtual world had a significant effect on VAS-rated relaxation only.*

[Freeman 2001] Freeman, J. and J. Lessiter. 2001. "Here, There, and Everywhere: The Effects of Multi-channel Audio on Presence." In *Proc. International Conference on Auditory Display*, 29 July–1 August, Espoo, Finland. 231–234. Also discussed in Lessiter (2001).

Factors:	Audio type (bass, no bass), number of audio channels (5, 2).
Visual display:	28-in. color television (TV); participant positioned to provide visual angle of 29º.

Audio display: 2 to 5 speakers and a subwoofer positioned behind participant's seat.
Tracking: None.
Audio sequences: Sound mixes reflecting a moving car with recordings of engine effects, gear noise, noise of stones hitting base of car as car drove over dips in the road, and noises of bumps while driving over dips.
Visual sequence: Rally car sequence.
Experimental task: Listen to audio while viewing video.
Participants: 30 participant; 15 males; age range 18 to 44; mean age 28 yr.
Study design: Within-subjects.
Presence measures: ITC-SOPI, 3-item SUS Questionnaire.
Task-related measures: *18-item Media Experience Questionnaire (MEQ).*
Findings:
(1) Use of bass had a significant effect on ITC-SOPI Sense of Physical Space, Engagement, and Ecological Validity subscales, with increased presence reported when bass signals were provided.
(2) Number of channels had no significant effect on ITC-SOPI scores.
(3) Use of bass had a significant effect on SUS scores, with more presence reported when bass was provided.
(4) Number of channels had no significant effect on SUS scores.
(5) Use of bass had a significant effect on MEQ ratings, with an increased experience indicated when bass was used for excitement, spaciousness, fullness, clarity, loudness, volume-related discomfort, fidelity, enjoyment, and overall rating. Number of channels had a significant effect on MEQ items enjoyment, with more enjoyment reported for 5 channels.

[Freeman 2000] Freeman, J., S.E. Avons, R. Meddis, D.E. Pearson, and W. Ijsselsteijn. 2000. "Using Behavioral Realism to Estimate Presence: A Study of the Utility of Postural Response to Motion Stimuli." *Presence*, 9(2), 149–164.

Factors: Stereopsis (present, absent), image motion (present, absent).
Computing platform: Two synchronized Panasonic M2 (A750-B) video players.
Visual display: AEA Technology 20-in. stereoscopic display consisting of 2 BARCO CPM 2053 color monitors with polarized filters, polarized glasses.
Tracking: Using Flock of Birds tracker placed around participant's neck.
Video sequence: Moving video comprised of a 100-sec. excerpt from rally car sequence filmed for ACTS MIRAGE *Eye to Eye* documentary using camera mounted on car hood, motion capable of evoking lateral postural responses. Still video consisted of frame from *Eye to Eye* footage, where camera situated by side of rally track awaiting rally car to drive by. Synchronized, nondirectional audio track consisting of sounds from car engine, gear changes, and clattering from stones hitting underside of car. Lower sound intensity used for still video.
Experimental task: View video. 4 trials.
Participants: 24 students; 12 males; mean age 25 yr.; mean height 1.75 m and stereoacuity ≥ 30 sec-arc or better.
Study design: Within-subjects.
Presence measures: Rating of presence on visual-analog scale, lateral postural response.
Task-related measures: *Rating of vection, rating of involvement, rating of sickness.*
Findings:
(1) Stereopsis had a significant effect on presence, with more presence reported for the stereoscopic image.
(2) Image motion had a significant effect on presence, with more presence reported for the moving video.
(3) Postural response had no significant correlation with presence.
(4) Image motion had a significant effect on postural response, with more movement occurring for participants watching the moving video.
(5) Stereopsis had no significant effect on postural response.

(6) *Stereopsis had a significant effect on involvement, with more involvement reported for the stereoscopic image. Image motion had a significant effect on involvement, with more involvement reported for the moving video.*

(7) *Image motion had a significant effect on vection, with more self-motion reported for the moving video. Stereopsis had no significant effect on vection.*

(8) *Image motion had a significant effect on sickness, with more sickness reported for the moving video. Stereopsis had no significant effect on sickness.*

[Freeman 1999 (1)] Freeman, J., S.E. Avons, D.E. Pearson, and W.A. Ijsselsteijn. 1999. "Effects of Sensory Information and Prior Experience on Direct Subjective Ratings of Presence." *Presence*, 8(1), 1–13.

Factors:	Stereopsis (present, absent), camera motion (observer, scene, minimal).
Computing platform:	Two Panasonic M2 (A750-B) video projectors.
Visual display:	AEA Technology 20-in. stereoscopic display consisting of 2 Barco CPM 2053 color monitors, viewed using polarized glasses.
Navigation:	None.
Object manipulation:	None.
Video content:	Three 30-sec. sections selected based on the amount of motion they contained.
Training:	3-min. practice trial.
Experimental task:	View video clips, providing continual reporting of presence.
Participants:	12 students; 6 males; mean age 22 yr.
Study design:	Within-subjects.
Presence measures:	Handheld slider ratings sampled at 5 Hz.
Findings: (1)	Stereopsis had a significant effect on presence, with more presence reported for stereoscopically viewed video.
(2)	Camera motion had a significant effect on presence, with more presence reported for observer motion than for minimal motion.

[Freeman 1999 (2)] Freeman, J., S.E. Avons, D.E. Pearson, and W.A. Ijsselsteijn. 1999. "Effects of Sensory Information and Prior Experience on Direct Subjective Ratings of Presence." *Presence*, 8(1), 1–13.

Factors:	Stereopsis (present, absent), camera motion (observer, scene, minimal).
Computing platform:	Two Panasonic M2 (A750-B) video projectors.
Visual display:	AEA Technology 20-in. stereoscopic display consisting of 2 Barco CPM 2053 color monitors, viewed using polarized glasses.
Navigation:	None.
Object manipulation:	None.
Video content:	Three 30-sec. sections selected based on the amount of motion they contained.
Training:	3-min. practice trial.
Experimental task:	View video clips, providing continual reporting of presence.
Participants:	12 students; 6 males; mean age 25 yr. Performed pre-rating of the continuous interest they had in the video sequences.
Study design:	Within-subjects.
Presence measures:	Handheld slider ratings sampled at 5 Hz.
Findings: (1)	Stereopsis and camera motion each had no effect on ratings of interest.
(2)	Stereopsis had no significant effect on presence.
(3)	Camera motion had a significant effect on presence and a significant interaction with stereopsis.

[Freeman 1999 (3)] Freeman, J., S.E. Avons, D.E. Pearson, and W.A. Ijsselsteijn. 1999. "Effects of Sensory Information and Prior Experience on Direct Subjective Ratings of Presence." *Presence*, 8(1), 1–13.

Factors:	Stereopsis (present, absent), camera motion (observer, scene, minimal), training (presence, interest, three-dimensionality).

Computing platform:	Two Panasonic M2 (A750-B) video projectors.
Visual display:	AEA Technology 20-in. stereoscopic display consisting of 2 Barco CPM 2053 color monitors, viewed using polarized glasses.
Navigation:	None.
Object manipulation:	None.
Video content:	Three 30-sec. sections selected based on the amount of motion they contained.
Training:	3-min. practice trial.
Experimental task:	View video clips, providing continual reporting of presence.
Participants:	72 participants; 36 males; mean age 24 yr.
Study design:	Within-subjects.
Presence measures:	Handheld slider ratings sampled at 5 Hz.
Findings: (1)	Stereopsis had a significant effect on presence, with increased presence reported for stereoscopic viewing.
(2)	Camera motion had no significant effect on presence but had a significant interaction with training group.
(3)	Training group had a significant effect, with participants trained in the 3-D rating giving higher ratings for presence.

[Garau 2003a] Garau, M., M. Slater, V. Vinayagamoorthy, A. Brogni, A. Steed, and M.A. Sasse. 2003. "The Impact of Avatar Realism and Eye Gaze Control on Perceived Quality of Communication in a Shared Immersive Virtual Environment." In *Proc. CHI 2003*, 5–10 April, Ft. Lauderdale, FL. Also discussed in Garau (2003b), Vinayagamoorthy (2004).

Factors:	Behavioral realism (inferred gaze, random gaze), photorealistism (photorealistic and gender-specific, stick-like), visual display (4-sided Cave, HMD).
Computing platform:	For ReaCTor system: SGI Onyx2 with eight 300-MHz R12000 MIPS processors, 8 GB RAM and 4 Infinite Reality2 graphics pipes. For HMD system: SGI Onyx with twin 196 MHz R10000, Infinite Reality Graphics and 192 MB main memory. Software implemented on derivative of DIVE 3.3x. Avatars H-Anim compliant.
Visual display:	One participant of each pair used a Trimenison ReaCTor with three 3 × 2.2 m walls and 3 × 3 m floor, and CrystalEyes stereo glasses. Partner used a Virtual Research V8 HMD with resolution 640 × 480 × 3, FOV 60º diagonal at 100% overlap.
Tracking:	Head and hand tracking using Intersense IS900 or Polhemus Fastrak.
Navigation:	Handheld device with 4 buttons (disabled) and joystick or with 5 button 3-D mouse.
Object manipulation:	None.
Virtual world:	Two large training rooms connected to a smaller meeting room between them. Self-representation provided for HMD participants. Avatars had identical functionality, with body movement based on participant's head and hand movements. For the inferred gaze condition, avatars used a "while speaking" and "while listening" eye animation model, with "at partner" gaze consistent with direction of participant's head.
Training:	Navigation training task. Doors from training room into meeting room opened when both participants in a pair felt comfortable.
Experimental task:	Role-playing negotiation task, where each pair were a mayor and a baker whose families were involved in a potentially volatile situation. Goal to reach a mutually acceptable conclusion within 10 min.
Participants:	48 BT Exact laboratory employees, grouped into same-gender pair; age range under 21 to over 50.
Study design:	Between-groups.
Presence measures:	5-item SUS Questionnaire, 5-item Social Presence Questionnaire, 2-item Co-presence Questionnaire.
Person-related meas.:	Social Avoidance and Distress (SAD) Social Anxiety Questionnaire, age, VE experience, VE knowledge, gender*, status*.

Task-related measures:		Quality of Communication Questionnaire with subscales: Face-to-Face, Involvement, 2-item Co-presence (see *Presence measures*), Partner Evaluation. *Rating of real and human-likeness of avatar, rating of understanding of partner's behavior and attitude.*
Findings:	(1)	Behavioral realism and photorealism had a significant effect on social presence and co-presence. Also had a significant interaction effect on social presence and co-presence, with the higher realism avatar used with inferred gaze yielding more presence; similarly on Face-to-face and Partner evaluation scores.
	(2)	Behavioral realism and photorealism each had no significant effect on SUS scores.
	(3)	Visual display had no significant effect on co-presence.
	(4)	Age had a significant positive correlation with quality of communication co-presence, social presence, co-presence, and SUS scores.
	(5)	SAD scores had no significant correlation with quality of communication co-presence, but a significant negative correlation with social presence, co-presence, and SUS scores.
	(6)	Gender had no significant correlation with any presence measure.
	(7)	VE experience had a significant negative correlation with SUS scores, VE knowledge a significant positive correlation.
	(8)	Social presence had a significant positive correlation with SUS scores.
	(9)	*VE experience had a significant negative relationship with perceived avatar fidelity.*
	(10)	*Behavioral realism and photorealism had a significant interaction effect on ratings of humanness of avatar and understanding of partner.*

[Garau 2003b (1)] Garau, M. 2003. *The Impact of Avatar Fidelity on Social Interaction in Virtual Environments*. Ph.D. Dissertation. University College London, UK.

Factors:	Agent responsiveness (talking, responsive, moving, static).
Computing platform:	SGI Onyx 2 with eight 300-MHz R12000 MIPS processors, 8 GB RAM and 4 Infinite Reality2 graphics pipes. DIVE-based software. Thought Technologies ProComp+ system for physiological monitoring and associated PC. Agents based on Criterion Software RenderWare models.
Visual display:	Trimension ReaCTor, three 3 × 2.2 m walls and 3 × 3 m floor, and CrystalEyes shutter glasses.
Tracking:	Head-tracking using Intersense IS900.
Navigation:	Using joystick with 4 buttons.
Object manipulation:	None.
Virtual world:	Library with 3 male and 2 female agents seated around a central table with books and papers. Several bookcases against the walls, book tables, and book trolleys. Agents exhibited gaze and postural behaviors. Static agents were frozen in a reading pose. Moving agents exhibited movements such as turning a page but not did respond to the participant. Responsive agents also changed position and engaged in gaze behavior when participant approached. For talking agents, the first agent approach would also speak to the participant (in a foreign language). Collision detection on library walls only.
Training:	Practice moving through virtual space in an area adjacent to the library.
Experimental task:	Explore the space preparatory to later reporting on experience. 4 min. allowed.
Participants:	41 participants; 24 males.
Study design:	Between-groups.
Presence measures:	5-item SUS Questionnaire, 5-item Co-presence Questionnaire, 5-item Self-Behavior Questionnaire, 4-item Perceived Agent Awareness Questionnaire, Δheart rate, Δskin conductance.
Person-related meas.:	SAD questionnaire, gender, computer usage, virtual reality (VR) experience, *2 mood-state questionnaires.*

Findings:	(1)	Agent responsiveness had no significant effect on presence.
	(2)	Agent responsiveness had a significant effect on only 1 item of co-presence. When computer usage considered, agent responsiveness had a significant effect on participants, with more presence reported for the responsive condition than the static condition, and participants with more computer usage reporting less presence.
	(3)	Presence had a significant positive correlation with co-presence.
	(4)	Agent responsiveness had a significant effect on self-behavior, with more social presence indicated for the responsive condition than for the static condition. SAD scores had a significant positive correlation with 1 item only.
	(5)	Agent responsiveness had a significant effect on perceived agent awareness, with more social presence indicated for talking and responsive conditions than for moving and static conditions. Gender and VR experience also had significant effects, with females and those with prior VR experience more likely to perceive agents as being aware.
	(6)	Gender and computer usage had no significant correlation with SUS scores or co-presence.
	(7)	Significant change in heart rate occurred only for participants in the responsive condition.
	(8)	Significant change in skin conductance occurred for participants in the talking, responsive, and moving conditions.

[Garau 2001] Garau, M., M. Slater, S. Bee, M.A. Sasse. 2001. "The Impact of Eye Gaze on Communication using Humanoid Avatars." In *Proc. SIGCHI '01*, 31 March–4 April, Seattle, WA. Also discussed in Garau (2003b).

Factors:		Behavioral realism (video, inferred gaze, random gaze, audio only).
Computing platform:		Dell Dimension XPST 550 (Pentium III) with GeForce 256 chipset, Gulillemot 3-D Prophet video card, Creative AWE32 sound card, running Windows 98. Compaq AP400 PIII 500 with GeForce 256 chipset, Elsa Gloria 2 video card, integrated sound, running Windows 98.
Visual display:		Video tunnel link providing face-on, head-and-shoulders view of partner, used a 21-in. Sony PVM-2130QM video monitor.
Audio display:		Senneheiser HD265 headphones. Sound recorded using an AKG C747 microphone placed on desk.
Tracking:		Head-tracking using Polhemus Isotrak II.
Navigation:		None.
Object manipulation:		None.
Virtual world:		Empty meeting room. In random gaze condition, timings and directions for avatar's head and eye movement randomly generated. In inferred gaze condition, eye animations based on audio stream based on "while speaking" and "while listening" modes based on dyadic conversation research.
Experimental task:		Role-playing task. One participant played role of mayor and the other that of a baker whose families had a conflict. Task was to reach a mutually acceptable solution within 10 min.
Participants:		100 BT Exact laboratory employees, grouped into same-gender pairs and matched for age.
Study design:		Between-groups.
Presence measures:		2-item Co-presence Questionnaire.
Person-related meas.:		*Gender, age*.
Task-related measures:		Quality of Communication Questionnaire with subscales: Face-to-Face, Involvement, Co-presence (see *Presence measures*), Partner Evaluation.
Findings:	(1)	Behavioral realism had a significant effect on co-presence, with presence scores in the video condition higher than those in the other conditions, followed by audio only, and then inferred gaze.

(2) Gender had no significant relationship with social presence.

(3) Behavioral realism had a significant effect on quality of communication Face-to-Face scores, with the video and inferred gaze conditions yielding more realistic conversation than the random gaze and neutral conditions. It also had a significant effect on the Involvement subscale, with the random gaze condition yielding less involvement than other conditions. For Partner Evaluation subscale, video condition scores were significantly higher than those in the random gaze condition, which scores were significantly higher than in either the random gaze or neutral conditions.

[Gerhard 2001] Gerhard, M., D.J. Moore, and D.J. Hobbs. 2001. "Continuous Presence in Collaborative Virtual Environments: Towards the Evaluation of a Hybrid Avatar-Agent Model for User Representation." In *Proc. International Conference on Intelligent Virtual Agents*, Madrid, Spain.

Factors:	Avatar realism (animated humanoid, animated cartoon-style, basic shapes).
Computing platform:	Avatars created using Avatara and Cybertown. Supported on Web using blaxxun Virtual World Platform community server.
Visual display:	Desktop monitors.
Object manipulation:	None.
Virtual world:	Art gallery using basic shapes for defining the geometry of the room and picture frames. Made available on the Web with avatar and chat interaction.
Experimental task:	Unanimously and collaboratively identify the art style (Cubist, Abstract, Naïve, Celtic, Psychedelic, Surreal) of a 4 contemporary artworks.
Participants:	27 participants, grouped into threes based on experience and immersive tendencies scores.
Study design:	Between-groups.
Presence measures:	22-item presence questionnaire focused on immersion, communication, involvement, awareness, and variables related to the nature of the environment and user interface. Completed over the Web.
Findings: (1)	Avatar realism had a significant effect on presence, with participants reporting more presence for the humanoid and cartoon-style avatars than for the basic shapes avatars.

[Heldal 2005] Heldal, I., R. Schroeder, A. Steed, A.-S. Axelsson, M. Spante, and J. Wideström. 2005. "Immersiveness and Symmetry in Copresent Situations." To appear in IEEE VR2005, Bonn, Germany.

Factors:	Type of environment [real, immersive projection technology (IPT) to HMD, IPT to desktop, desktop to desktop, IPT to IPT).
Computing platform:	One IPT system used SGI Onyx2 Infinite Reality with fourteen 250-MHz R10000 MIPS processors, 2 GB RAM, and 3 graphics pipes. Other IPT system used SGI Onyx2 with eight 300-MHz R12000 MIPS processors, 8 GB RAM and 4 Infinite Reality2 graphics pipes. IPT systems used DIVE software. HMD system used PTC Division, Ltd. Mockup software. Desktop system used SG O2 with 1 MIPS R10000 processor and 256 MB RAM, dVise 6.0 software. Robust Audio Tool for audio communication. Network lag < 180 ms.
Visual display:	VR-CUBE 3 × 3 × 3 m with CrystalEyes shutter glasses; Trimension ReaCTor 2 2.8 × 2.2 m walls and 2.8 × 2.8 m floor with CrystalEyes shutter glasses; n-Vision Datavisor 10x with 640 × 480 resolution, FOV 87º H × 50º V; 19-in. monitor.
Audio display:	Wired headset with microphone.
Tracking:	Head and hand tracking using Polhemus and Intersense devices (IPT).
Navigation:	Using 3-D wand or joystick (IPT), pinch gloves (HMD), mouse (desktop).
Object manipulation:	Using 3-D wand or joystick (IPT), pinch gloves (HMD), mouse (desktop).
Virtual world:	Room with cubes. Participants represented by simple avatar with jointed arm. Participants in immersive conditions saw only virtual hand.

Training:		Practice in marking and picking up objects, navigation, use of devices and use of audio. 5 to 10 min.
Experimental task:		Working in pairs, solve puzzle involving eight 30 × 30 × 30 cm blocks with different colors on different sides by arranging blocks so that each side of assembled blocks displays a single color. 20 min. allowed.
Participants:		220 participants, grouped into pairs.
Study design:		Between-subjects.
Presence measures:		2-item SUS Questionnaire, 2-item Co-presence Questionnaire.
Task-related measures:		*Rating own and partner's contribution to task in three areas*, *collaboration questionnaire*, *usability questionnaire*.
Performance measures:		*Time to complete*.
Findings:	(1)	Type of environment had a significant effect on presence only for the IPT-to-desktop condition, with more presence reported for IPT.
	(2)	Type of environment had a significant effect on co-presence, with more co-presence reported by participants in the IPT-to-IPT and IPT-to-HMD conditions than the IPT-to-desktop and desktop-to-desktop conditions.
	(3)	Presence had no significant correlation with co-presence.
	(4)	*Type of environment had no significant effect on collaboration.*
	(5)	*Type of environment had a significant effect on nonverbal contribution to task in the IPT-to-HMD and IPT-to-desktop conditions.*
	(6)	*Type of environment had no significant effect on usability for the IPT-to-desktop condition.*

[Hendrix 1996a (1)] Hendrix, C. and W. Barfield. 1996. "Presence Within Virtual Environments as a Function of Visual Display Parameters." *Presence*, 5(3), 274–289.

Factors:		Head-tracking (present, absent).
Computing platform:		SGI Extreme workstation.
Visual display:		GE-610 6 × 8 ft. rear-projection screen, stereoscopic viewing using Stereographics Corp. CrystalEyes shutter glasses. Images generated with 1280 × 512 pixel resolution, standard conditions were GFOV 50°. (Shutter glasses also worn in monoscopic condition with disparity set to zero.) Eyepoint elevation 110 cm. Subject seated/standing so position subtended a 90° FOV.
Tracking:		Polhemus 3Space Fastrak for head-tracking.
Navigation:		Standard mouse placed on table in front of subject.
Object manipulation:		None.
Virtual worlds:		10 × 10 m virtual room with checkerboard patterned floor and several familiar objects such as tables and chairs, a bookshelf, a soda machine, a photocopier machine, and paintings.
Experimental task:		Navigate around room to become familiar with the environments in order to answer questionnaire previously made available. No time limit.
Participants:		12 university students; 6 males; mean age 27 yr. Same participants used in [Hendrix, 1996a (2), (3)].
Study design:		Within-subjects.
Presence measures:		4-item questionnaire, including overall presence rating, 1 item on sense of "being there," 1 item on realism, 1 item on responsiveness.
Findings:	(1)	Head-tracking had a significant positive effect on each measure of presence.
	(2)	Head-tracking had a significant positive effect on realism and responsiveness.
	(3)	Realism of interaction and response each had a significant positive correlation with presence rating and sense of "being there."

[Hendrix 1996a (2)] Hendrix, C. and W. Barfield. 1996. "Presence Within Virtual Environments as a Function of Visual Display Parameters." *Presence*, 5(3), 274–289.

Factors: Stereopsis (present, absent).
Computing platform: Study design. As in [Hendrix 1996a (1)].
Presence measures: 5-item questionnaire, including overall presence rating, 1 item on sense of "being there," 1 item on realism of response, 1 item on realism of depth/volume, 1 item an ability to reach into VE.
Findings:
(1) Stereopsis had a significant positive effect on each measure of presence.
(2) Stereopsis had a significant positive effect on rating of realism of depth/volume and ability to reach into VE; and no significant effect on rating of realism of response.
(3) Realism of response, realism of depth/volume, and ability to reach into VE each had a significant positive relationship with presence rating and sense of "being there."

[Hendrix 1996a (3)] Hendrix, C. and W. Barfield. 1996. "Presence Within Virtual Environments as a Function of Visual Display Parameters." *Presence*, 5(3), 274–289.

Factors: Geometric FOV (90°, 50°, 10°).
Computing platform: Study design. As in [Hendrix 1996a (1)], except used 3 virtual worlds.
Presence measures: 6-item questionnaire, including overall rating, 1 item on sense of "being there." Remainder consisted of 1 item on realism of virtual world, 1 item on object compression/magnification, 1 item on narrowness/width, 1 item on proportional correctness.
Findings:
(1) GFOV had a significant effect on each measure of presence, realism and proportional correctness, with reported presence higher for GFOV 50° than for GFOV 10° and for GFOV 90° than for GFOV 10°.
(2) GFOV had no significant effect on perceived object compression/magnification and narrowness/width.
(3) Realism and perception of proportionally correct each had a significant positive correlation with presence rating and sense of "being there;" perception of compression/magnification and view each had no significant correlation with either measure of presence.

[Hendrix 1996b (1)] Hendrix, C. and W. Barfield. 1996. "The Sense of Presence Within Auditory Virtual Environments." *Presence*, 5(3), 290–301.

Factors: Audio cues (spatialized sound, no sound).
Computing platform: SGI Indigo Extreme workstation. Crystal River Engineering Beachtron audio spatialized card in 386 PC.
Visual display: GE-610 6 × 8 ft. rear-projection screen, stereoscopic viewing using Stereographics Corp. CrystalEyes shutter glasses. Images generated with 1280 × 512 pixel resolution. Subject seated to achieve 90° H FOV, 50° GFOV.
Audio display: Yamaha YH-1 orthodynamic headphones, with radio signal delivered via a Realistic receiver/amplifier. Soda machine sounds obtained using an Ensoniq digital sound sampler. Sounds uncorrelated with actions in VE.
Experimental task: As in [Hendrix 1996a (1)].
Participants: 16 university students; 14 males; mean age 29.9 yr. 4 participants had participated previously in presence-related studies.
Study design: Within-subjects.

Presence measures: 3-item questionnaire, including overall rating, 1 item on sense of "being there," and 1 item on realism of virtual world.

Findings:
(1) Audio cues had a significant effect on each measure of presence, with increased presence reported for spatialized sound.
(2) Realism had a significant positive effect on overall presence rating and sense of "being there."

[Hendrix 1996b (2)] Hendrix, C. and W. Barfield. 1996. "The Sense of Presence Within Auditory Virtual Environments." *Presence*, 5(3), 290–301.

Factors: Audio cues (spatialized sound, nonspatialized sound).
Computing platform: Study design: as in [Hendrix 1996b (1)].
Presence measures: 5-item questionnaire, including overall rating, 1 item on sense of "being there," 1 item on realism of virtual world, 1 item on realism of interaction with sound sources, and 1 item on emanation of sound from specific locations.

Findings:
(1) Audio cues had a significant positive effect on each measure of presence, with increased presence reported for spatialized sound.
(2) Realism in appearance, interaction, and localization had a significant positive effect on overall presence rating and sense of "being there."

[Hofmann 2001] Hofmann, J., T.J. Jäger, T. Deffke, and H. Bubb. 2001. "Effects of Presence on Spatial Perception in Virtual Environments." Presented at the 4th Annual International Workshop on Presence, 21–23 May, Philadelphia, PA.

Factors: Immersion factors (high, low), pictorial realism (high, low).
Computing platform: SGI Onyx2 graphics engine.
Visual display: 5-sided rear-projection system with 3 walls, ceiling, and floor each 2.5 m. Screen resolution 1020 × 1020. Refresh rate 114 Hz. Viewed using StereoGraphics CrystalEyes shutter glasses. Display adjusted for individual's IPD.
Audio display: None.
Tracking: Head-tracking using Ascension Technologies 6 DOF MotionStar.
Navigation: None.
Object manipulation: Tubular hand-held device used for immersion scaling tasks by pressing a button and simultaneously rotating the device.
Virtual world: Virtual front half of a passenger car interior, with a real driving seat and steering wheel. High pictorial realism version provided a high level of 3-D detailing and was completely textured in color; low realism version details such as switches, safety belts were omitted, no textures were used, uniform colors were used. Immersion factors were frame rate, interactivity, duration of exposure, vividness of scene, mental priming, real-world ambient light, real-world background noise, and communication with instructor.
Training: None.
Experimental task: While seated in the real driver's car, provide verbal directions to adjust the size of the virtual car cockpit until it matched the memorized size of an actual car cockpit previously seen. Three different scaling procedures used in 3 sessions: uniform 3-D scaling, one-dimensional (1-D) horizontal scaling, partial 1-D vertical scaling. Presence questionnaire completed while immersed.
Participants: 77 participants (mainly passenger car development engineers); 68 males; age range 20 to 60.
Study design: Between-subjects.
Presence measures: Modified IPQ.
Task-related measures: *Kennedy's SSQ*.
Performance measures: Size estimation error for each type of scaling.

Findings: (1) IPQ Spatial Presence and Reality Appraisal subscales had a significant correlation with size estimation error when the uniform scaling method was used. IPQ Involvement subscale had a significant correlation with size estimation error when partial vertical scaling method was used.

[Hoffman 1999] Hoffman, H.G, A. Hollander, K. Schroder, S. Rousseau, and T. Furness III. 1999. *Physically Touching, and Tasting Virtual Objects Enhances the Realism of Virtual Experiences*. Human Interface Technology Laboratory, University of Washington, Seattle, WA.

Factors: Olfactory cues (biting candy bar, imagining biting candy bar).
Computing platform: Division, Ltd. ProVision 100 system.
Visual display: Division, Ltd. dVisor HMD with FOV 40° V × 105° H, 40° overlap.
Tracking: Polhemus sensors attached to fingerless bicycle glove and to real candy bar.
Navigation: None.
Object manipulation: Using 3-D wand.
Virtual world: Division, Ltd. KitchenWorld demo with virtual candy bar. Self-representation as virtual hand.
Experimental task: Examine kitchen for 1 min. Then close eyes while experimenter tears off part of the wrapper and places candy bar in participant's hand. Open eyes and smell candy bar. In biting condition, take a bite out of the candy bar; in imagine condition only, imagine taking a bite.
Participants: 21 university students.
Presence measures: Questionnaire.
Findings: (1) Olfactory cues had a significant positive effect on presence.

[Hoffman 1998] Hoffman, H.G., J. Groen, J. Prothero, and M.J. Wells. 1998. "Virtual Chess: Meaning Enhances Users' Sense of Presence in Virtual Environments." *Inter. Journal of Human-Computer Interaction*, 10(3), 251–263.

Factors: Meaning (meaningful chess position, meaningless chess position), task expertise (nonchess player, weak player, strong player, tournament-level player).
Computing platform: Provision 100 reality engine.
Visual display: Division, Ltd. dVisor HMD with FOV 40° V × 105° H, 40° overlap.
Tracking: Polhemus 6 DOF head and mouse tracking.
Navigation: Only by moving head to change coordinates and get a closer view of chessboard.
Object manipulation: Using 3 DOF mouse.
Virtual world: Virtual chessboard on a wooden floor. Tartakower and DuMont's 16 middle game positions were used as meaningful stimuli. The chess pieces from each middle game were rearranged in a random manner to create 16 meaningless positions.
Training: Familiarization with VEs and interface devices by 5-min. playing time on Division, Ltd. SharkWorld game.
Experimental task: Each participant presented with 16 chess positions—each labeled meaningful or meaningless—and told to memorize the positions. 1 min. for each set of positions.
Participants: 33 participants from a university and a city chess club.
Study design: Within-subjects for meaning; between-subjects for chess expertise.
Presence measures: 4-item questionnaire.
Task-related measures: Memory accuracy on identifying 16 studied chessboard positions (8 meaningful and 8 meaningless) among 32 presented positions.
Findings: (1) Meaningfulness had a significant positive effect on presence.
(2) Task expertise had no significant main effect on presence. A significant interaction was found with meaningfulness such that nonchess players showed no significant effect for meaningfulness, but all other classes of players showed a significant positive effect of meaningfulness on presence.

(3) *Meaningfulness and task expertise had a significant positive effect on memory accuracy. A significant interaction between these was found, such that tournament players were significantly more accurate on meaningful positions, whereas no significant difference was found for all other classes of task expertise.*

[Hoffman 1996] Hoffman, H., J. Groen, S. Rousseau, A. Hollander, W. Winn, M. Wells, and T. Furness. 1996. *Tactile Augmentation: Enhancing Presence in Virtual Reality with Tactile Feedback from Real Objects*. Technical Report 96-1. Human Interface Technology Laboratory, University of Washington, WA.

Factors:	Haptic cues (mixed reality with physical objects, virtual objects only).
Computing platform:	Division, Ltd. ProVision 100 system.
Visual display:	Division, Ltd. dVisor HMD with FOV 40° V × 105° H, 40° overlap.
Tracking:	Position sensor attached to hand.
Object manipulation:	3 DOF mouse with trigger button used to 'pick-up' object.
Virtual world:	Included models of 8 real items (e.g., butter knife) with texture mapping. Self-representation as virtual hand.
Experimental task:	Observe some objects, observe and touch other objects.
Participants:	14 university students.
Study design:	Within-subjects.
Presence measures:	5-item questionnaire.
Findings: (1)	Haptic cues had a significant positive effect on presence.

[Huijnen 2004] Huijnen, C.A.G.J., W.A. Ijsselsteijn, P. Markopoulos, and B. de Ruyter. 2004. "Social Presence and Group Attraction: Exploring the Effects of Awareness Systems in the Home." *Cognition, Technology and Work*, 6(1), 41–44.

Factors:	Level of detail (full video, sketchy visual, no visualization), social (group, alone).
Visual display:	TV.
Tracking:	None.
TV:	Sports event program, 1974 soccer game of Dutch national team. Visualization of friends (depending on condition), no audio connection.
Experimental task:	Watch show with visualization of friends depending on condition.
Participants:	34 male participants, usually in groups of three friends.
Study design:	Within-subjects for type of visualization, between-subjects for viewer type.
Presence measures:	Slightly adapted IPO-Social Presence Questionnaire (IPO-SPQ).
Task-related measures:	*Group Attitude Scale*.
Findings: (1)	Level of detail had a significant effect on IPO-SPQ subjective attitude statements and semantic differential scales, with more presence reported for full video than for either sketchy visual or no visualization of friends.
(2)	Viewer type had no significant effect on presence.
(3)	*Type of visualization had a significant effect on group attitude, with full video yielding more group attraction.*

[Hullfish 1996] Hullfish, K. 1996. *Virtual Reality Monitoring: How Real is Virtual Reality?* M.Sc. Dissertation. Human Interface Technology Laboratory, University of Washington, Seattle, WA.

Factors:	Environment type (real, virtual, imagined).
Computing platform:	Division, Ltd. Provision 100 system with dVise software. Geometry created using 3-Dstudio and Macromodel. Lighting simulated using directional and ambient light, metallic surfaces simulated.
Visual display:	Stereoscopic Division, Ltd. dVisor HMD with FOV 105ºH × 41ºV. Subject's height was simulated. Experimental area curtained off.
Navigation:	Using single button on 3-D joystick.

Object manipulation: Pointing to objects using virtual hand.

(Virtual) world: Each world had a 12 × 12 ft. chessboard in the middle of the floor, and four 14 × 14 × 14 in. identical objects (cubes, half cylinders, 3-D "T"s, or 3-D triangles) of different colors (red, purple, yellow, and blue) arranged in a pattern on the chessboard. Four sets of 8 worlds were developed. Each arrangement was 1 of 8 distinct global shapes (e.g., curve, trapezoid). Four sets of 8 worlds were developed, experienced in either virtual world, real, or imagined condition. (Imagined was the same as the real condition, except objects were not present and had to be imagined based on written instructions.) In the virtual world, ceiling and stone walls were texture mapped with photographs from RE. Details included electrical outlets, conduits, and switches. Self-representation as virtual hand.

Training: Play Division, Ltd. SharkWorld game to become familiar with the equipment and navigational controls. Two practice trials in each type of environment.

Experimental task: In the study phase, for each of 24 worlds, participants memorize (and later report) the spatial configuration of the 4 objects and the position of this global shape on the chessboard while navigating a pre-defined path and pointing to each object as they passed it. Then play in a Chemistry World VE for 15 min. In the test phase, for each of 32 worlds presented on a PC, determine whether that world had been seen previously and, if so, in what type of environment.

Participants: 16 university community participants; 6 males; age range 20 to 38 yr. No experience in VE technology.

Study design: Within-subjects.

Presence measures: Virtual Reality Monitoring, Memory Characteristic Questionnaire (MCQ).

Task-related measures: *Item on MCQ concerned with cognitive effort.*

Performance measures: *Items on MCQ concerned with rating memories of real, virtual, and imagined environments*.

Findings:

(1) Environment type had a significant effect on the "sense of being there" and "being surrounded by objects," with higher ratings reported for the REs than for the virtual or imagined environments, which were not significantly different.

(2) Environment type had no significant effect on the "sense of visiting rather than seeing an environment," on "remembering being a spectator rather than a participant," or "awareness of my body."

(3) For old/new recognition, environment type had no significant effect on frequency with which worlds were misrecognized as new. Participants missed new worlds significantly more frequently than any other worlds from another origin and were as likely to miss virtual and imagined worlds than to identify them correctly as old.

(4) For correct identification of origin, environment type had a significant effect, with virtual worlds identified correctly less frequently than real, imagined, or new worlds. These worlds more frequently assigned as real rather than imagined or new.

(5) Environment type had a significant effect on cognitive effort, with experience in imagined worlds being rated as more difficult, virtual less difficult, real easiest. Real and virtual memories were rated as the most similar.

[Ijsselsteijn 2004] Ijsselsteijn, W.A., Y.A.W de Kort, R. Bonants, J. Westerink, and M. de Jager. 2004. "Virtual Cycling: Effects of Immersion and a Virtual Coach on Motivation and Presence in a Home Fitness Application." In *Proc. Virtual Reality Design and Evaluation Workshop 2004*, 22–23 January, University of Nottingham, UK.

Factors: Interaction/immersion (high, low), virtual coach (present, absent).

Visual display: Wall-mounted screen.

Navigation: In high immersive condition, using bicycle handlebars and biking velocity.

Object manipulation: None.

Virtual world: Highly immersive world provided visualization of a person cycling on a racing bicycle through a landscape. Every minute, a female virtual coach would encourage participants to do better, tell them they were doing great, or tell them to slow down a little, based on participant's measured heart rate. In low immersive condition, presentation of abstract picture of a racetrack in bird's eye view, with a dot indicating the position of the bicycle. Participant seated on racing cycle placed on a training system with variable resistance.

Experimental task: Bicycle through environment. 4 sessions (ITC-SOPI and Intrinsic Motivation Inventory (IMI) completed after each session).

Participants: 24 Philips Research Eindhoven employees; 12 males; mean age 41.3 yr. None engaged in frequent physical exercise.

Study design: Within-subjects.

Presence measures: ITC-SOPI.

Task-related measures: IMI with 6 subscales, *mean bicycle velocity*.

Findings:

(1) Interaction/immersion had a significant effect on each ITC-SOPI subscale, with high immersion giving increased scores for Spatial presence, Engagement, and Ecological validity, and lower scores for Negative effects.

(2) Virtual coach had a significant effect on ITC-SOPI Spatial presence and Negative effects subscales, with presence of coach leading to more spatial presence and less negative effects.

(3) ITC-SOPI Spatial presence, Engagement, and Ecological Validity subscale scores had a significant correlation with IMI Interest/enjoyment, Perceived control, and Pressure/Tension subscale scores.

(4) Interaction/immersion had a significant effect on IMI Interest/enjoyment, Perceived Competence, Value/Usefulness, and Perceived Control subscale scores, with high immersion giving increased motivation.

(5) Virtual coach had a significant effect on IMI Value/Usefulness and Perceived Control subscale scores, with presence of the coach giving increased motivation.

(6) Interaction/immersion had a significant effect on mean average bicycle velocity, with high immersion yielding increased velocity. Virtual coach had no significant effect on mean velocity.

[Ijsselsteijn 2001a] Ijsselsteijn, W., H. de Ridder, J. Freeman, S.E. Avons, and D. Bouwhuis. 2001a. "Effects of Stereoscopic Presentation, Image Motion, and Screen Size on Subjective and Objective Corroborative Measures of Presence." *Presence*, 10(3), 298–311.

Factors: Stereopsis (present, absent), image motion (present, absent), horizontal screen size (50º, 28º).

Computing platform: PC to control 2 Panasonic M2 (A750-B) video players and tracker. Custom software.

Visual display: Curved stereoscopic projection screen 1.9 × 1.45 m, providing FOV 50ºH, with polarized glasses.

Tracking: Using Flock of Birds tracker placed around participant's neck.

Video sequence: Moving video comprised 100-sec. excerpt from rally car sequence filmed for ACTS MIRAGE *Eye to Eye* documentary using camera mounted on car hood, motion capable of evoking lateral postural responses. Still video consisted of frame from *Eye to Eye* footage, where camera situated by side of rally track awaiting rally car to drive by. Synchronized, nondirectional audio track consisting of sounds from car engine, gear changes, and clattering from stones hitting underside of car. Lower sound intensity used for still video.

Experimental task: View video. 4 trials.

Participants: 24 students; 11 males; age range 18 to 30; mean age 23.5 yr. Height under 1.85 m. and stereoacuity ≥ 30 sec-arc or better.

Study design: Within-subjects for image motion and stereopsis, between-subjects for screen size (with reference to Freeman (2000) data).

Presence measures:		Rating of presence on visual-analog scale, lateral postural response (data reported on 16 participants).
Task-related measures:		*Rating of vection, rating of involvement, rating of sickness.*
Findings:	(1)	Stereopsis had a significant effect on rating of presence, with more presence reported for stereoscopic presentation.
	(2)	Image motion had a significant effect on rating of presence, with more presence reported for moving video scene.
	(3)	Screen size had a significant interaction with motion, such that FOV had an effect only for the motion sequence, when more presence was reported for the larger FOV.
	(4)	Stereopsis and image motion had no effect on postural response, though a significant interaction between road type and stereopsis and motion was found for curved section of the road.
	(5)	Presence scores had no significant correlation with postural responses.
	(6)	Screen size had no significant correlation with postural response.
	(7)	*Stereopsis had no significant effect on rating of vection, involvement, or sickness.*
	(8)	*Image motion had a significant effect on rating of vection and involvement but not sickness.*
	(9)	*Screen size had no significant effect on rating of vection.*

[Ijsselsteijn 2001b] Ijsselsteijn, W., I. Bierhoff, and Y. Slangen-de Kort. 2001b. "Duration Estimation and Presence." Presented at Presence 2001, 21–23 May, Philadelphia, PA.

Factors:		Directional information (map, text), range of information (complete route, per subgoal, per decision point).
Computing platform:		Intel Pentium II PC. Sense8 Corp. WorldUp software.
Visual display:		17-in. desktop monitor.
Navigation:		Using cursor keys on keyboard.
Object manipulation:		None.
Virtual world:		Included a route navigation system that offered real-time directional information as either text or a map.
Experimental task:		Navigate through a 3-D maze. 3 trials.
Participants:		44 students; 32 males; age range 20 to 26.
Study design:		Within-subjects for range of information, between-subjects for directional information.
Presence measures:		4-item presence questionnaire.
Task-related measures:		*Time to complete*, duration estimation, judged speed.
Findings:	(1)	Direction information had no significant effect on presence.
	(2)	Duration estimation (corrected for differences in time taken) had no significant correlation with presence.
	(3)	Judged speed had a significant positive correlation with presence.
	(4)	*Duration estimation and judged speed each had a significant positive correlation with time to complete.*

[Insko 2001 (2)] Insko, B.E. 2001. *Passive Haptics Significantly Enhances Virtual Environments*. Ph.D. Dissertation. University of North Carolina at Chapel Hill, NC.

Factors:	Haptic cues (practice in mixed-reality maze, practice in unaugmented virtual maze).
Computing platform:	SGI Onyx2, with 1 Infinite Reality2 Engine with 4 R12000 processors, 4 raster managers, and 64 MB of texture memory. Mean system lag 110 ms. In-house software.
Visual display:	Virtual Research V8 HMD, with FOV 60° diagonal at 100% stereo overlap, 640 × 480 tri-color pixel resolution per eye. Update rate generally 20–30 Hz.

Audio display:	Real radio placed in location of virtual radio and used to give instructions to participants. A hand colliding with a virtual object caused a sound (different sounds for right and left hand (such a collision also changed block color to red) in the unaugmented virtual maze condition only.
Haptic display:	Solid objects made of styrofoam and cardboard used to define maze path.
Tracking:	Head-tracking using University of North Carolina (UNC) Tech Hi-Ball, allowing movement in 4 × 10 m area. Hand and knee tracking using Polhemus FastTraks.
Navigation:	Actual walking.
Object manipulation:	Joystick with push buttons.
Virtual world:	Room furnished with rectangular colored objects forming a single-path maze, where path consisted of 11 turns. Patterned textures used on floor, walls, and ceiling.
Training:	None.
Experimental task:	Complete 3 clockwise laps through the environment, touching all objects, while trying to get a sense of the layout. Then, while blindfolded, complete 1 lap in equivalent real-world maze, this time without touching objects.
Design:	Between-subjects.
Participants:	33 undergraduate computer science students; 17 males; age range 19 to 23.
Study design:	Between-subjects.
Presence measures:	Witmer-Singer PQ.
Person-related meas.:	Guilford-Zimmerman Spatial Orientation Test, gender.
Performance measures:	*Cognitive sketch maps, height estimation of 4 objects, estimated distance between two objects. In RE: time to complete lap, number of object collisions, number of wrong turns*.
Finding: (1)	Haptic cues had no significant effect on presence.
(2)	Gender had no significant effect on presence.
(3)	Spatial orientation score had no significant effect on presence.
(4)	*Haptic cues had a significant positive effect on completion time, number of collisions, distance estimation accuracy, and number of attempted wrong turns (with improved performance when haptic cues were present).*
(5)	*Haptic cues had no significant effect on sketch map accuracy and height estimation accuracy.*

[Jang 2002] Jang, D.P., I.Y. Kim, S.W. Nam, B.R. Wiederhold, M.D. Wiederhold, and S.I. Kim. 2002. “Analysis of Physiological Response to Two Virtual Environments: Driving and Flying Simulation.” *CyberPsychology*, 5(1), 11–18.

Factors:	Virtual world type (simple/flying, complex/driving).
Computing platform:	Driving simulator used Pentium 600 PC with 3-D accelerator graphics card. Physiological measurements captured using an I-330 C-2 computerized biofeedback system from J&J Engineering.
Visual display:	VFX3-D HMD.
Haptic display:	Subwoofer in flight seat used for flying in the virtual world and vibration chair used for driving in the virtual world. Both driven using sound from computer.
Tracking:	Head-tracking used for each virtual world.
Navigation:	Steering wheel used for driving in the virtual world only.
Virtual world:	Flying in the virtual world developed for treating the fear of flying. Participant in window seat in the passenger cabin of a commercial aircraft experiences different parts of a flight. Driving in the virtual world consists of an urban street, secluded road, and a long tunnel with traffic jam; traffic lights, traffic sounds that copy those in the real world.
Training:	For flying in the virtual world, look around plane to get oriented. For driving simulator, instruction in use of controls.
Experimental task:	For flying in the virtual world, experience sitting in plane, taxiing, taking off, flying in good weather, flying in bad weather, and landing. For driving in the

	virtual world, follow traffic through different road areas while an operator controls the level of traffic. 15 min.
Study design:	Within-subject.
Participants:	11 nonphobic participants over 18 yr. old.
Presence measures:	%Δskin resistance, %Δheart rate, %Δskin temperature. 12-item Presence and Realism Questionnaire.
Person-related meas.:	Tellegen Absorption Scale (TAS), Dissociative Experience Scale (DES), *age*.
Task-related measures:	*SSQ*.
Findings: (1)	Type of virtual world had a significant effect on any presence measure.
(2)	There was no significant correlation between either TAS or DES scores and any measure of presence.
(3)	*Type of virtual world had no effect on SSQ scores.*
(4)	*Age had a significant positive correlation with SSQ scores but only after experiencing the driving task.*

[Johnson 1995] Johnson, D.M. and D.C. Wightman. November 1995. *Using Virtual Environments for Terrain Familiarization; Validation*. Research Report 1686. U.S. Army Research Institute for the Behavioral and Social Sciences.

Factors:	Detail level (Hanchey Army Heliport, portion of Arizona).
Computing platform:	Simulator Training Research Advanced Testbed for Aviation (STRATA).
Visual display:	Stereoscopic, fiber-optic helmet-mounted display with FOV 127ºH × 66ºV, resolution 5 arcminutes for background and 1.5 arcminutes for high-resolution insets in the center of the visual field, luminance > 35 ft. lamberts, contrast ratio 50:1. Helmet individually fitted and optically aligned for each participant. Update rate 60 Hz. Participant seated in an AH-64A Apache helicopter pilot cockpit simulator with all flight instruments/controls/motion displays switched off or covered by a black blanket. Black curtain surrounded cockpit area.
Audio display:	Intercom system.
Tracking:	Infrared (IR) head-tracking system.
Navigation:	Joysticks attached to right and left arms of seat to control up/down or left/right movement, with button to reposition participant to a preset VE location.
Object manipulation:	None.
Virtual world:	(1) Hanchey Army Heliport (HAH) at Fort Rucker (Alabama). 'T'-shaped area with dimensions approximately 0.5 × 0.7 mi., including all features relevant to flight training missions, with structure colors matched from photos or videotape, signs and logos texture mapped onto buildings. Area included 19 helipads with parking ramps, taxi lanes, and overrun areas; 30 (semi-) permanent buildings, control tower, beacon tower, antenna pole, 3 windsocks, 4 fuel tanks; and miscellaneous objects such as fire trucks, water tank, satellite receiver dish. One each of 4 types of helicopters cycled continuously through its respective traffic patterns.
	(2) Portion of Arizona taken from STRADA's Arizona database. Approximately 10 x 10 mi. Area centered east of Phoenix and included part of Mesa. Contained urban, residential, and desert terrain, with appropriate types and densities of buildings, businesses, churches, houses, towers, playgrounds, cars, roads, parking lots, signs, streams, and vegetation; no moving models.
	Both virtual worlds had a large, red 3-D cursor in lower center FOV pointing to magnetic north. Participants were represented in each virtual world by a black 2.5 × 3 ft. virtual carpet they could see underneath their seat and feet when they looked down.
Training:	Familiarization with cockpit, helmet-mounted display, and 3-min. practice using joysticks.
Experimental task:	Self-guided exploration of either HAH or Arizona VE. Three 30-min. sessions.

Participants:		12 soldiers from aviation units at Fort Rucker; males 10; age range 20 to 23; mean age 28.3 yr. None had previously visited the HAH.
Presence measures:		32-item Witmer-Singer PQ Version 2.0.
Findings:	(1)	Level of detail had no significant effect on presence.

[JISC 2000] Joint Information Systems Committee (JISC) Technology Applications Programme. February 2000. *JTAP Project 305—Human Factors Aspects of Virtual Design Environments in Education: Project Report.* Advanced VR Research Center, Loughborough University, UK.

Computing platform:		Division, Ltd. ProVision 100 system, with dVS Version 3.1.2.
Visual display:		Division, Ltd. HMD.
Tracking:		Polhemus Fastrak for head-tracking.
Navigation:		Using Division, Ltd. 3-D mouse.
Object manipulation:		Using Division, Ltd. 3-D mouse.
Virtual world:		Tool box.
Experimental task:		Perform a series of create, link, and animation operations according to a predefined task list to develop virtual scenes.
Participants:		18 participants.
Presence measures:		10-item presence section on VRUSE Questionnaire, also includes 11 items related to simulation fidelity.
Findings:	(1)	Quality of simulation had a significant positive correlation with the sense of immersion, the sense of "being present," and the overall feeling of being present in the VE.
	(2)	Fidelity of the VE had a significant positive correlation with sense of being immersed.
	(3)	A belief that the quality of the simulation improved performance had a significant positive correlation with the sense of presence and the overall feeling of "being present" in the VE.
	(4)	Accuracy of simulation had a significant positive correlation with both the sense of immersion and the sense of presence.

[Kim 2004] Kim, J., H. Kim, M. Muniyandi, M.A. Srinivasan, J. Jordan, J. Mortensen, M. Oliveira, and M. Slater. 2004. "Transatlantic Touch: A Study of Haptic Collaboration Over Long Distance." *Presence*, 13(3), 328–337.

Factors:	Haptic force feedback (present, absent), pointer directional information (present, absent).
Computing platform:	Dual 0.9-GHz PC 256-MB RAM, with NVIDIA GeForce2-based graphics card at one site, running Microsoft Windows NT; 1-GHz PC 512 Mb RAM, with NVidia GeForce2-based graphics card at other site, running Microsoft Windows 2000. Sites connected with Internet2 network with round-trip time of 90 ms. SensAble Technologies GHOST Software Development Kit and OpenGL development software.
Visual display:	19-in. monitor at each site.
Object manipulation:	SensAble Technologies PHANTOM force-feedback device at each site, with update rate 1000 Hz, 6 DOF motion, 3 DOF force feedback.
Virtual world:	Room containing a cube and 2 probes. Walls of room constrain cube movement. Gravity set of 9.8 m/s^2 and high dynamic and static coefficients of friction between cube and walls and between cube and pointers.
Training:	Practice lifting block for a few minutes.
Experimental task:	Approach the box and cooperate (with an experimenter) to lift it by exerting pressure upwards and toward one side of the box only, then keep the box off the ground as long as possible. 2 min. allowed.
Participants:	20 participants.

Study design: Between-groups.
Presence measures: *Presence questionnaire*, 7-item Co-presence Questionnaire.
Person-related meas.: Age.
Findings:
(1) Haptic force feedback had a significant effect on co-presence, with more co-presence reported when force feedback was present.
(2) Directional information had a significant effect on co-presence, with less co-presence reported when directional information was present.
(3) Age had a significant effect on co-presence, with less co-presence reported for older ages.

[Knerr 1994 (1)] Knerr, B.W., S.L. Goldberg, D.R. Lampton, B.G. Witmer, J.P. Bliss, J.M. Moshell, and B.S. Blau. 1994. "Research in the Use of Virtual Environment Technology to Train Dismounted Soldiers." *Journal of Interactive Instruction Development*, Spring, 9–20.

Factors: Navigation (joystick, spaceball).
Computing platform: Two 486 50-MHz PCs with Intel DVI display boards. Sense8 Corp. WorldToolkit.
Visual display: Virtual Research Corp. flight helmet.
Tracking: Polhemus Isotrack for head-tracking.
Navigation: Gravis joystick or Spaceball Tech spaceball.
Virtual world: Virtual Environment Performance Assessment Battery (VEPAB) world.
Experimental task: Complete 20 tasks from VEPAB battery, ranging from vision to reaction time tests.
Participants: 24 participants, primarily college students.
Presence measures: Witmer-Singer PQ.
Person-related meas.: Witmer-Singer ITQ.
Task-related measures: Kennedy SSQ.
Performance measures: *Completion time for locomotion task, object manipulation task, tasking tasks.*
Findings:
(1) ITQ score had no significant correlation with PQ score.
(2) SSQ Total score had a significant negative correlation with PQ score.
(3) Type navigation had a significant effect on completion time for locomotion and object manipulation tasks, with quicker time found for joystick, but no significant effect on completion time for tracking tasks.

[Laarni 2005] Laarni, J., N. Ravaja, and T. Saari. 2005. "Presence Experience in Mobile Gaming." Presented at the Digital Games Research Conference—*DIGRA 2005 Conference: Changing Views: Worlds in Play*. 16–20 June, Vancouver, British Columbia, Canada.

Factors: Device type [PC, Personal Digital Assistant (PDA)].
Computing platform: Dell Precision 350 computer with Panasonic Liquid Crystal Display (LCD) Projector PT-LC75E. Handheld Compaq iPAQ PDA.
Visual display: Large screen 1.3 × 1.7 m or 8 × 6 cm.
Tracking: None.
Navigation: PC keyboard or pad.
Virtual world: Colin McRae Rally or V-Rally game.
Training: Practice with game for 5 min.
Experimental task: Play rally game for ~ 5 min., restarting as necessary.
Participants: 50 participants; 17 males; age range 19 to 39; mean age 27 yr.
Study design: Between-subjects.
Presence measures: Measures, Effects, Conditions-Spatial Presence Questionnaire (MEC-SPQ).
Person-related meas.: Witmer-Singer ITQ.
Findings:
(1) Device type had a significant effect on MEC-SPQ Spatial situation model, Self-location, and Possible Actions subscales, with participants using PDA reporting lower presence.
(2) Device type had a significant interaction with ITQ Focus subscale for predicting MEC-SPQ Suspension of disbelief scores, with those in the PC condition with high

Focus scores reporting more suspension of disbelief, whereas in the PDA condition, those with low Focus scores reporting more suspension.

(3) Device type had a significant interaction with ITQ Games subscale for predicting MEC-SPQ Attention allocation scores, with those low Games scores reporting more engagement in the PDA condition, while those with high Games scores reported more attention in the PC condition.

[Lampton 2001] Lampton, D.R., D.P. McDonald, M.E. Rodriguez, J.E. Cotton, C.S. Morris, J. Parsons, and G. Martin. March 2001. *Instructional Strategies for Training Teams in Virtual Environments*. Technical Report 1110. U.S. Army Research Institute for the Behavioral and Social Sciences. Alexandria, VA.

Factors:	Instructional strategy (demonstration, coaching, replay, no feedback).
Computing platform:	SGI Onyx RE2 with 8 processors/3 pipes, SGI Onyx RE2 with 4 processors/1 pipe, SGI Indigo High Impact, SGI Indy, Dell Pentium 90, Dell 486. Audio capture and playback using a Dell Optiplex 560 PC running Windows 95 with Sound Blaster AWE64.
Visual display:	Two Virtual Reality Corp. VR4 HMDs.
Audio display:	HMD headphones.
Tracking:	Two 6-tracker Ascension Technologies MotionStars for tracking body position, gaze, and locomotion.
Navigation:	Walking-in-place, with participant standing within a circular barrier.
Object manipulation:	Palm grip of a Gravis Blackhawk joystick with thumb switch to cycle through an array of configurable hand held items. Index finger trigger.
Virtual world:	10 rooms positioned along a hallway containing one 90° turn. Six floor plans, differing in directions in which hallways branch and location of rooms. Seventh floor plan with a multistory structure. Gas canisters. Avatars depict a person in hazardous materials (HAZMAT) gear, incorporates 45 DOF beads for realistic deflection of limbs and torso, raising and lowering legs synchronized to participant locomotion, articulating right arm synchronized to participant's arm movement. VE supports action-after critique system that provides a playback mechanism. Sound cues: gun shots, door opening/closing, collision sounds, and communications with team members.
Training:	Two virtual worlds for practice in walking in a VE and for practice using the manual control device to select and use equipment. First world consists of a large room and a connecting series of corridors. Second world contains examples of various types of equipment, friendlies, enemies, and neutrals that can be encountered during missions, participant practice using the pistol and necessary equipment. Each training mission took 8 min. No feedback group performed 2 trials in second practice environment. Demonstration group watched replay of mission performed by experienced team, followed by practice session. Replay group performed one practice mission followed by watching replay of their performance. Coaching group was provided prompts or suggestions as team conducted 2 practice missions.
Experimental task:	Working in 2-person teams, search for canisters containing hazardous gas and, if necessary, deactivate canisters. Computer-generated enemy and innocent bystanders moved through hallways and rooms. Air supply limited to 8 min. Rules define order in which rooms are searched, team formation for room entry, actions on contact with enemy and innocent bystanders, assign areas of responsibility within a room, and how/what to report on the radio network.
Participants:	81 participants recruited from local colleges; approximately 45% male; age ranged 17 to 52; mean age 21 yr. Presence data collected from only 40 participants.
Study design:	Between-subjects.
Presence measures:	32-item Witmer-Singer PQ Version 2.0.
Person-related meas.:	29-item ITQ Version 2.0.
Performance measures:	*Task completion time*.

Findings:	(1)	ITQ Total score had no significant correlation with PQ Total.
	(2)	*Instructional strategy had no significant effect on task completion time.*

[Larsson 2004] Larsson, P., D. Västfjäll, and M. Kleiner. 2004. "Perception and Self-Motion in Auditory Virtual Environments." In M. Alcaniz and B. Ref (Eds.), *7th Annual International Workshop: Presence 2004*. Valencia, Spain: Universidad Politecnica de Valencia. 252–258.

Factors:		Auralization quality (anechoic rendering, marketplace), number of concurrent sound sources (3, 1), input source sound (still, moving, artificial), turn velocity (20, 40, 60º per sec.).
Computing platform:		Acoustic simulations rendered offline in Computer-Aided Theatre Technique (CATT)-Acoustic v 8 using Walkthrough Convolver, with generic Head-Related Transfer Functions (HRTFs).
Visual display:		None.
Auditory display:		Beyerdynamic DT-990Pro circumaural headphones driven by a NAD Electronics amplifier.
Tracking:		None.
Navigation:		None.
Object manipulation:		None.
Virtual world:		Marketplace in Tübingen, Germany, with binaural simulations of a virtual listener standing in one place and rotating a certain number of laps. 3 still sound sources used were a bus on idle, a small fountain, and a barking dog; 3 moving source were footsteps, a bicycle, and a driving bus; 3 artificial sources were a stationary pink noise and differing pink noise bursts. Participant seated.
Training:		None.
Experimental task:		Verbally report direction of motion.
Participants:		26 participants; 13 males; mean age 24 yr.
Study design:		Within-subjects for auralizarion quality and number of concurrent sound sources, between-subjects for input sound source.
Presence measures:		Magnitude estimation measure of presence, rating of realism.
Task-related measures:		*Rating of vection intensity and convincingness, count of vection experiences.*
Findings:	(1)	For single sounds, only input source had a significant effect on presence, with more presence reported using magnitude estimation for still sounds than for moving or artificial sounds. There was a significant interaction between sound source, and auralization quality had a significant effect on presence, with both the still and moving sound sources receiving higher ratings in the marketplace condition.
	(2)	For multiple sound sources, sound source had a significant effect on presence reported using magnitude estimation, with greater presence reported for still and moving sources than for artificial sounds; velocity had a significant effect with more presence reported for 60º/s than for other velocities; and quality had a significant effect, with more presence reported for the marketplace environment than for the anechoic environment.
	(3)	For multiple sound sources, sound source had a significant effect on realism, with artificial sounds rated less real than still and moving sounds; quality had a significant effect, with the marketplace environment rated more realistic than the anechoic environment.
	(4)	*For single sounds in the marketplace condition, type of sound source number had a significant effect on the number of vection experiences, with more vection reported for still sources than either moving or artificial sources. For single sounds, turn velocity had no significant effect on amount of vection.*
	(5)	*For single sounds, sound source only had a significant effect on vection intensity, with more vection occurring for still sources. Sound source and quality each had a significant effect on ratings of vection convincingness, with more convincing vection reported for still sounds and marketplace quality.*

[Larsson 2001] Larsson, P., D. Västfjäll, and M. Kleiner. 2001. "The Actor-Observer Effect in Virtual Reality Presentations." *CyberPsychology & Behavior*, 4(2), 239–246.

Factors:		Interaction (actor, observer).
Computing platform:		PIII-600 NT workstation with the ELSA(R) Inc. ELSA Gloria XXL graphics board. Model created using CATT-Acoustic and transferred to EON Studio. Auditory scene rendered using Lake Technologies Aniscape software, CP4 hardware.
Visual display:		For actor condition, a Sony Glasstron HMD in stereoscopic mode. For observer condition, screen. All participants seated approximately 2 m from projection screen.
Audio display:		For actor condition, Beyerdynamic DT990 headphones. For observer condition, Sennheiser HD 414 headphones.
Tracking:		For actor condition, Polhemus Fastrak for head-tracking.
Navigation:		Logitech Wingman regular joystick.
Object manipulation:		None.
Virtual world:		Model of Orgryte Nya Kyrka church in Gothenburg, Sweden. Some textures and two avatars. Auditory source was "Swanee River" performed by a female singer and visually represented as female avatar moving along a predetermined path in the church. Visual and auditory stimuli synchronized between female avatar and actor.
Training:		Instruction on use of joystick and HMD.
Experimental task:		For actor condition, count the number of windows in the church, find 4 different balls positioned in the church, and then return to starting position. A sentence appears when a participant moves close to a ball, with the color of the text the same as the color of the next ball to be found. Task took about 10 min. Also requested to remember each piece of text.
Participants:		32 undergraduate or graduate students; 23 males; mean age 24.3 yr.
Study design:		Between-subjects.
Presence measures:		4 presence questions (naturalness of interaction, extent of presence, extent of involvement, extent things did and happened naturally without much mental effort), part of the SVUP questionnaire.
Task-related meas.:		*Awareness of external/internal factors, sound quality, enjoyment, simulator sickness.*
Findings:	(1)	Interaction had a significant effect on presence questions, with actors reporting higher presence than observers.
	(2)	Interaction had a significant effect on enjoyment questions, with actors reporting higher presence than observers.
	(3)	*Interaction had a significant effect on external awareness, with observers reporting higher awareness than actors, and a significant effect on internal awareness, with actors reporting more awareness than observers.*
	(4)	*Interaction had no significant effect on ratings of sound quality.*
	(5)	*Interaction had a significant effect on dizziness and headaches, with actors reporting more symptoms than observers but had no significant effect on nausea, eye train, problems concentrating, or feeling unpleasant.*

[Lawson 1998] Lawson, J.P. September 1998. *Level of Presence or Engagement in One Experience as a Function of Disengagement From a Concurrent Experience*. M.Sc. Thesis. Naval Postgraduate School, Monterey, CA. Also discussed in Darken (1999).

Factors:	Visual display (Mini-Cave, HMD, flat screen), audio cues (present, absent), directions (attend to VE and videotape, attend to VE).
Computing platform:	SGI Onyx RE-2 workstation with four 194 IP 25-MHz MIPS R10000 processors, Infinite Reality graphic board, 128-MB 20-way leaved main memory, 4-MB

	texture memory, 1-MB secondary cache, Iris Audi Processor Version A2. Coryhpheaus Software Designer's Workbench, EasyTerrain and EasyScene, and Multigen software.
Visual display:	Virtual Research V8 HMD with resolution 640 × 3 × 480, FOV 60º, frame rate 18–24 fps; semi-circular mini-Cave using 3 Mitsubishi Model VS5071 40-in. rear-projection screens with FOV 103º, frame rate 24 fps; 21-in. SGI Color monitor with resolution 1280 × 1024, FOV 33º, frame rate 30 fps. 20-in. monitor for viewing videotape. Participant seated with monitor for videotape display placed just off to the side in clear view.
Audio display:	Headphones, attached to HMD as appropriate.
Tracking:	Polhemus 3Space Fastrak for head-tracking.
Navigation:	None.
Object manipulation:	None.
Virtual world:	Variation of H.G. Wells' *War of the Worlds* sited in SGI Performer Town.
Videotape:	Aardman Animations Ltd. short subject *Wallace and Gromit* videotape.
Training:	None.
Experimental task:	While on an automated car tour, observe the invasion of the town and various events. Videotape started a few minutes before the start of VE guided tour.
Participants:	70 participants; 52 males; mean age 37 yr.
Study design:	Between-subjects.
Presence measures:	Engagement scores: VE quiz score, RE quiz score, 32-item Witmer-Singer PQ Version 2.0.
Person-related meas.:	Witmer-Singer ITQ.
Findings: (1)	Visual display had no significant effect on engagement score and VE quiz score but had a significant effect on RE quiz scores, with higher engagement found for mini-Cave than for the HMD condition.
(2)	Directions had a significant effect on engagement scores and RE quiz scores, with participants who were directed to attend to both the VE and real world achieving lower scores; but no significant effect on VE quiz scores.
(3)	Audio cues had no significant effect on engagement scores, but a significant positive effect on VE and RE quiz scores.
(4)	VE quiz scores had a significant positive correlation with PQ scores.
(5)	*ITQ had no significant correlation with VE quiz scores.*

[Lee 2004] Lee, S., G.J. Kim, G.S. Sukhatme, and C.-M. Park. 2004. "Effects of Haptic Feedback on Telepresence and Navigational Performance." In *Proc. ICAT 2004*.

Factors:	Force rendering (environmental and collision preventing, environmental, no force feedback).
Computing platform:	Activmedia Pioneer 2-DX mobile robot equipped with 1 SICK AG LMS-200 laser scanner for front coverage, 8 Polaroid 600 series ultrasonic transducers for rear coverage, Sony EVID-30 camera.
Haptic display:	SensAble PHANTOM.
Training:	In a virtual world equivalent to the real-world test condition, navigate a virtual robot represented as a cube with a top-center-positioned virtual camera providing a 45° FOV, 640 × 480 resolution, front-facing laser scanner, rear-facing sonar array. Trained once for each force rendering method.
Experimental task:	Navigate the robot through a RE from a start to a goal position as safely as possible. 3 trials.
Participants:	12 participants; 10 males; age range 23 to 37 yr.
Study design:	Within-subject.
Presence measures:	3-item presence questionnaire.
Task-related measures:	Perceived performance, *2-item force perception questionnaire*.
Performance measures:	Number of collisions, time to complete.

Findings:	(1)	Force rendering method had a significant effect on presence, with more presence reported for the environmental and collision preventing and environmental only conditions.
	(2)	Perceived performance had a significant positive correlation with presence.
	(3)	Number of collisions had no significant correlation with presence.
	(4)	*Force rendering method had no significant effect on time to complete.*
	(5)	*Force rendering method had a significant effect on number of collisions, with environment and collision preventing force feedback resulting in few collisions.*
	(6)	*Perceived performance had a significant negative correlation with the number of collisions.*

[Lee 2003 (1)] Lee, K.M. and C. Naas. 2003. "Designing Social Presence of Social Actors in Human Computer Interaction." In *Proc. SIGCHI Conference on Human Factors in Computing Systems*. 289–296.

Factors:		Participant personality (extrovert, introvert), computer voice personality (extrovert, introvert).
Computing platform:		PC with Internet Explorer 4.0 browser.
Visual display:		Monitor.
Audio display:		Headphone.
Virtual world:		Web site for book buying that presents 5 books using a visual interface with a link to an audio file for book descriptions. Extrovert voice had a speech rate of 216 words/min., 140-Hz fundamental frequency, 40-Hz pitch range. Introvert voice had a speech rate of 184 words/min., volume level 15% of other, 84-Hz fundamental frequency, 16-Hz pitch range.
Experimental task:		Read instructions on Web site and listen to audio descriptions of books.
Participants:		72 undergraduate students; gender approximately balanced. Selected as having extreme extrovert or extreme introvert scores on a both Myers-Briggs and Wiggins personality tests.
Study design:		Between subjects.
Presence measures:		4-item Social Presence Questionnaire.
Person-related meas.:		Gender.
Task-related measures:		*Extrovertedness/Introvertedness of voice questionnaire*.
Findings:	(1)	Participant personality had no significant effect on social presence.
	(2)	Computer voice personality had a significant effect on social presence, with more presence reported for the extrovert voice. Also, participant personality had a significant interaction effect on social presence. Extrovert participants reported more social presence for the extrovert computer voice, and introvert participants reported more presence for the introvert computer voice.
	(3)	Gender had no significant relationship with social presence.
	(4)	*Computer voice personality had a significant effect on Extrovertedness/ Introvertedness ratings, with the extrovert voice rated as more extroverted. Participant personality had no significant effect.*

[Lee 2003 (2)] Lee, K.M. and C. Naas. 2003. "Designing Social Presence of Social Actors in Human Computer Interaction." In *Proc. SIGCHI Conference on Human Factors in Computing Systems*. 5–10 April, Fort Lauderdale, FL. 289–296.

Factors:	Participant personality (extrovert, introvert), computer voice personality (extrovert, introvert), item description (extrovert, introvert).
Computing platform:	PC with Internet Explorer 4.0 browser.
Visual display:	Monitor.
Audio display:	Headphone.
Virtual world:	Web site for online auction similar to E-Bay, providing names and pictures for 9 items and a link to an audio file that gave item descriptions. Extrovert voice had

		speech rate of 216 words/min., 140-Hz fundamental frequency, 40-Hz pitch range. Introvert voice had 184 words/min., volume level 15% of other, 84-Hz fundamental frequency, 16-Hz pitch range.
Experimental task:		Read instructions on Web site and listen to audio descriptions of items.
Participants:		80 undergraduate students; gender approximately balanced. Selected as having extreme extrovert or extreme introvert scores on both Myers-Briggs and Wiggins personality tests.
Study design:		Between-subjects.
Presence measures:		4-item Social Presence Questionnaire.
Person-related meas.:		Gender.
Task-related measures:		*Extrovertedness/Introvertedness of voice questionnaire*.
Findings:	(1)	Computer voice personality had a significant effect on social presence, with more presence reported for the extrovert voice. Also, participant personality had a significant interaction effect on social presence. Extrovert participants reported more social presence for the extrovert computer voice, and introvert participants reported more presence for the introvert computer voice.
	(2)	Computer voice personality and item description had a significant interaction effect on social presence. The extrovert voice narrating extrovert text induced greater presence than when reading introvert text and vice versa.
	(3)	Gender had no significant relationship with social presence.
	(4)	*Computer voice personality had a significant effect on Extrovertedness/Introvertedness ratings, with the extrovert voice rated as more extroverted. Participant personality had no significant effect. Item description had a significant effect on Extrovertedness/Introvertedness ratings, with the extrovert description rated as more extroverted.*

[Lessiter 2001] Lessiter, J. and J. Freeman. 2001. "Really Hear? The Effects of Audio Quality on Presence." Presented at the 4th Annual International Workshop on Presence, 21–23 May, Philadelphia, PA.

Factors:		Audio mix (5 channels and bass, stereo, mono).
Visual display:		100-Hz Phillips 28-in. color TV, with viewing distance to render 29º visual angle display.
Audio display:		Left and right speakers or 5 speakers surrounding participant and bass speaker behind seat.
Tracking:		None.
Audio sequences:		Sound mixes reflecting a moving car, with recordings of engine effects, gear noise, noise of stones hitting base of car as car drives over dips in the road, and noises of bumps while driving over dips.
Visual sequence:		Rally car sequence.
Experimental task:		Listen to audio while viewing video.
Participants:		18 students and college staff; 9 males; age range 20–57; mean age 30.8 yr.
Study design:		Within-subjects.
Presence measures:		ITC-SOPI, 6-item SUS Questionnaire.
Task-related measures:		*Audio Experience Questionnaire (AEQ)*, *identification of favorite audio mix*.
Findings:	(1)	Audio mix had a significant effect on ITC-SOPI Engagement scores, with more presence reported for 5 channels with bass than for stereo or mono audio—scores for which did not differ significantly.
	(2)	Audio mix had a significant effect on SUS scores, with more presence reported for 4 channels with bass than for stereo or mono audio—scores for which did not differ significantly.
	(3)	*Audio mix had a significant effect on AEQ scores, with a better experience reported for the 5.1 mix for spaciousness/surrounding, loudness, discomfort associated with loudness, enjoyment, and overall rating items.*
	(4)	*The 5.1 mix was selected as favorite much more frequently than other mixes.*

[Lin 2004] Lin, J.J.W., H. Abi-Rached, and M. Lahav. 2004. “Virtual Guiding Avatar: An Effective Procedure To Reduce Simulator Sickness in Virtual Environments.” In *Proc. SIGCHI Conference on Human Factors in Computing Systems*. 24–29 April, Vienna, Austria. 719–726.

Factors:		Motion predictor avatar (non-earth-fixed with turn cues, earth-fixed with turn cues, earth-fixed without turn cues, no prediction).
Computing platform:		Real Drive driving simulator including a full-size Saturn car, three 800 × 600 pixel Sony Superdata Multiscan VPH-1252Q projectors, and a motion platform.
Visual display:		Panoramic three 230 × 175 cm screen display with horizontal FOV (HFOV) 220º, viewed using CrystalEyes stereo glasses.
Navigation:		None.
Object manipulation:		None.
Virtual world:		University of Illinois Crayolaland cartoon world with a cabin, pond, flowerbeds, and a forest. A Virtual Guiding Avatar (VGA) in the form of an abstract airplane hovered centrally, facing the forward direction, predicting coming motion.
Training:		2-min. practice trial viewed on monitor.
Experimental task:		In car, take 120-sec. guided drive through Crayolaland on a quasi-circular trajectory that included left and right turns and forward and rearward translations. 4 trials with different starting points.
Participants:		10 Human Interface Technology Lab personnel; 5 males; age range 20 to 31.
Study design:		Within-subjects.
Presence measures:		9-item Engagement, Enjoyment, and Immersion (E^2I) scale; with 4 factors (sensory, distraction, realism, control); includes 1-item structure of memory test score and 5-item Enjoyment.
Task-related measures:		*Kennedy SSQ, perceived sharpness of turns, ability to predict turns*.
Performance measures:		(See *Presence measures*: part of E^2I scale).
Findings:	(1)	Motion predictor had a significant effect on presence, with more presence reported for non-earth-fixed with turn cues and earth-fixed with turn cues than for no prediction.
	(2)	*Motion predictor had a significant effect on SSQ scores, with less symptoms reported for non-earth-fixed with turn cues and earth-fixed with turn cues than for no prediction.*
	(3)	*Motion predictor had a significant effect on enjoyment, with more enjoyment reported for earth-fixed with turn cues than for no prediction.*
	(4)	*Motion predictor had a significant effect on perceived sharpness of turns, with the perception that turns were less sharp for earth-fixed with turn cues.*
	(5)	*Motion predictor had no significant effect on ability to predict turns.*

[Lin 2002] Lin, J.J.W., H.B.L. Duh, D.E. Parker, H. Abi-Rached, and T.A. Furness. 2002. “Effects of Field of View on Presence, Enjoyment, Memory, and Simulator Sickness in a Virtual Environment.” In *Proc. Virtual Reality 2001*. 13–17 March. 235–240.

Factors:	FOV (180º, 140º, 100º, 60º).
Computing platform:	Real Drive driving simulator including a full-size Saturn car, three 800 × 600 pixel Sony Superdata Multiscan VPH-1252Q projectors, and motion platform.
Visual display:	Panoramic three 230 × 175 cm screen display with HFOV 220º, viewed using CrystalEyes stereo glasses.
Navigation:	None.
Object manipulation:	None.
Virtual world:	University of Illinois Crayolaland cartoon world with a cabin, pond, flowerbeds, and a forest.
Training:	2-min. practice trial viewed on monitor.

Experimental task:		In car, take 120-sec. guided drive through Crayolaland on a quasi-circular trajectory that included left and right turns and forward and rearward translations. 4 trials with different starting points.
Participants:		10 Human Interface Technology Lab personnel; 5 males; age range 20 to 31.
Study design:		Within-subjects.
Presence measures:		9-item E^2I scale; with 4 factors (sensory, distraction, realism, control); includes 1-item structure of memory test score and 5-item Enjoyment.
Task-related measures:		Kennedy SSQ.
Performance measures:		(See *Presence measures*: part of E^2I scale).
Findings:	(1)	FOV had a significant effect on presence, with more presence reported for 180º than for 100º and more presence reported for 100º FOV than for 60º.
	(2)	FOV had a significant effect on SSQ, with more symptoms reported for larger FOVs.
	(3)	Memory performance and presence had a significant positive correlation.
	(4)	Enjoyment had no significant correlation with presence.
	(5)	Presence and SSQ scores had a significant positive correlation.
	(6)	Enjoyment and SSQ scores had a significant negative correlation.

[Lok 2003a] Lok, B., S. Naik, M. Witton, and F.P. Brooks, Jr. 2003. "Effects of Handling Real Objects and Avatar Fidelity on Cognitive Task Performance in Virtual Environments." In *Proc. IEEE Virtual Reality 2003 Conference*, 22–26 March, Los Angeles, CA. 125–132.

Factors:		Haptic cues (VE with real objects, VE with virtual objects), self-representation (generic with rubber gloves, visually faithful).
Computing platform:		SGI Reality Monster, using 1 rendering pipe at 20 fps for pure VE condition and 4 rendering pipes at 12–20 fps for hybrid condition. 4 NTSC resolution cameras for a 320 × 240 resolution reconstruction. Latency .03 sec. and 1-cm reconstruction error.
Visual display:		Virtual Research V8 HMD with 640 × 480 resolution per eye for VE. Television for real world.
Tracking:		UNC Hi-Ball tracker for head-tracking, with Polhemus Fastrak trackers for Pinch gloves.
Object manipulation:		Using Fakespace Pinch gloves in VE with virtual objects. Using yellow dishwashing gloves in hybrid VE.
Virtual world:		Virtual room including a lamp, a plant and a painting, and a virtual table registered with a real Styrofoam table. Participant standing in front of table on which blocks were placed. Self-representation in purely VE condition was neutral gray, generic. Self-representation in hybrid VE included accurate shapes and generic appearance or visually faithful appearance.
Training:		Practice task in real world using 6-block patterns (viewing blocks on television only), and 4-block patterns in VE.
Experimental task:		Block arrangement task based on the Wechsler Adult Intelligent Scale, involving reasoning, problem solving, and spatial visualization. Involved small 4-block patterns and large 9-block patterns in 10 patterns (6 real timed, 4 VE timed).
Participants:		40 participants; 33 males. Taken, or enrolled in, a higher level mathematics course.
Study design:		Between-subjects.
Presence measures:		Expanded SUS Questionnaire.
Person-related meas.:		Guilford-Zimmerman Aptitude Survey Part 5: Spatial orientation.
Task-related measures:		*Kennedy SSQ, self-rating of task performance*.
Performance measures:		*Time to correctly replicate given patterns*.
Findings:	(1)	Haptic cues and self-representation each had no significant effect on presence.
	(2)	*Haptic cues had a significant effect on performance, with improved performance for the hybrid VE as compared with the VE with virtual objects.*
	(3)	*Self-representation had a significant effect on task performance, with improved performance for the visually faithful self-representation vs. the VE with virtual*

objects but had no significant effect for the hybrid VE with generic self-representation.

(4) *Experimental conditions had a significant effect on self-reports of performance, with higher reported performance for the hybrid VE with visually faithful self-representation than for the VE with virtual objects and generic self-representation.*

(5) *Experimental conditions had no significant effect on SSQ scores.*

(6) *Spatial ability had no relationship with task performance.*

[Lok, 2003b] Lok, B., S. Naik, M. Whitton, and F.P., Brooks, Jr. 2003b. “Effects of Handling Real Objects and Self-Avatar Fidelity on Cognitive Task Performance and Sense of Presence in Virtual Environments.” *Presence: Teleoperators and Virtual Environments,* 12(6), 615–628.

Factors:	Mixed reality (real blocks, virtual blocks), self-avatar fidelity (visually faithful, generic).
Computing platform:	SGI Reality Monster, with 1 to 4 graphic rendering pipes (depending on condition) to provide > 20 fps for virtual objects and > 12 fps for reconstructing real objects. 4 cameras to generate virtual images of real objects in real time.
Visual display:	Virtual Research V8 HMD with resolution 640 × 480.
Tracking:	3rdTech, Inc. HiBall tracker for head-tracking. For pinchgloves, using Polhelus Fastrak trackers.
Object manipulation:	Fakespace pinchgloves.
Virtual world:	Room containing several virtual objects and a table that was registered with a real table. Four or nine 3-inch cubes with different patterns on sides positioned on table. Self-representation of hands as real appearance. Unaugmented virtual world had no collision detection.
Training:	6 practice trials in real world, 4 practice trials in virtual world.
Experimental task:	Block arrangement task based on portion of Wechsler Adult Intelligence Scale measuring reasoning, problem solving, and spatial visualization. Perform 6 timed trials in real world using camera to see blocks and then 4 timed trials in appropriate VE. Yellow dishwashing gloves used to handle blocks in augmented virtual world with low fidelity.
Participants:	40 participants. Have taken or are enrolled in a higher-level math course.
Study design:	Between-subjects.
Presence measures:	SUS Questionnaire, 2 items related to avatar appearance.
Person-related meas.:	Guilford-Zimmerman Spatial Orientation.
Task-related measures:	Self-assessment of task performance.
Performance measures:	*Difference in time to replicate target pattern in the VE compared with RE.*
Findings: (1)	Self-avatar fidelity had no significant effect on presence.
(2)	Mixed reality had no significant effect on presence.
(3)	*Mixed reality had a significant effect on task performance, with participants using real blocks conditions completing the task faster than those using virtual blocks.*
(4)	*Self-avatar fidelity had no significant effect on task performance.*
(5)	*Mixed reality had a significant effect on self-assessment of task performance, with those in the visually faithful hybrid environment (VFHE) condition reporting better performance than those in the purely virtual environment (PVE) condition.*

[Mania 2004] Mania, K. and A. Robinson. 2004. “The Effect of Quality of Rendering on User Lighting Impressions and Presence in Virtual Environments.” Presented at the ACM SIGGRAPH International Conference on VR Continuum and Its Applications in Industry, Nanyang Technological University (NTU), Singapore. 200–205.

Factors:	Rendering quality (high quality, mid quality, low quality).
Computing platform:	PC-based with graphics card. WorldUp with software that monitored participants’ head movements. Average frame rate 12 fps.

Visual display:	Kaiser ProView 30 stereoscopic HMD, with 30º diagonal FOV. Adjusted for participants' IPD.
Tracking:	Head-tracking.
Virtual world:	Academics' office, with objects such as shelves, books, chairs, a computer, and a desk and a single ceiling-mounted light source. Navigation restricted to 360º circle around the set viewpoint and 180º vertically.
Experimental task:	Look around the virtual office for 45 sec.
Participants:	36 postgraduate students; 28 males.
Study design:	Between subjects.
Presence measures:	3-item SUS Questionnaire.
Task-related measures:	Responses to Lighting Questionnaire. Kennedy SSQ.
Findings: (1)	Rendering quality had no significant effect on presence.
(2)	Responses to lighting had a significant positive correlation with presence.

[Mania 2003] Mania, K., T. Troscianko, R. Hawkes, and A. Chalmers. 2003. "Fidelity Metrics for Virtual Environment Simulations Based on Spatial Memory Awareness Tests." *Presence*, 12(3), 296–310.

Factors:	Environment type (real, HMD mono head-tracked, HMD stereo head-tracked, monitor, HMD with mono mouse, desktop monitor).
Computing platform:	Frame rate 14 fps.
Visual display:	Kaiser Pro-View 30 HMD and 21-in. desktop monitor with mask, both providing 30º FOV, 640 × 480 resolution. IPD used to adjust HMD.
Audio display:	None.
Tracking:	Head-tracking.
Navigation:	By rotating in a swivel chair.
Object manipulation:	None.
Virtual world:	4 × 4 m room with a different landmark on each wall: a door and shelves, door and greenboard, whiteboard, small shelves at each end. Room also contained light fixtures, several tables, a swivel chair, and 21 primitive objects of approximately the same size. All objects were painted the same color. Photorealistic representation, with dimensions accurate to 1 cm and luminosity equivalent to real room. Texture mapping on doors and tables only.
Training:	None.
Experimental task:	Participants guided to the real or virtual room and seated in the swivel chair. 3 min. to observe the room.
Participants:	21 undergraduate and M.Sc. students; 16 males. Frequent computer users.
Study design:	Between-subjects.
Presence measures:	6-item SUS Questionnaire.
Performance measures:	*Memory Recall, Confidence, and Awareness State Questionnaire completed after exposure and for 1-week retention test.*
Findings: (1)	Environment type had no significant effect on presence.
(2)	*Environment type had no significant effect on memory recall or confidence.*
(3)	*Testing session had a significant effect on memory recall and confidence, with lower scores reported for the retention test.*

[Mania 2001a] Mania, K. and A. Chalmers. 2001. "The Effects of Levels of Immersion on Memory and Presence in Virtual Environments: A Reality Centered Approach." *CyberPsychology & Behavior*, 4(2), 247–263.

Factors:	Environment type (real, HMD, 3-D desktop, audio-only).
Visual display:	Custom see-through, nonstereoscopic HMD with FOV approximately 30ºH, resolution 1024 × 764. 21-in. monitor with FOV approximately 35ºH, resolution 1152 × 864. Average update rate 45 fps. Rendered flat-shaded.
Tracking:	None.

Navigation:		For visual conditions, using standard mouse to explore room from a steady viewpoint, approximately placed in center of room, with ability to move in a full circle.
Object manipulation:		None.
Virtual world:		Model of a university seminar room, including slide show to present 12 “overhead” slides synchronized with audio taken from digital video recording from real condition.
Experimental task:		Attend a 15-min. seminar on a nonscience topic. (Real condition included presentation of 12 slides on an overhead projector.)
Participants:		4 groups of 18 participants from a university campus and Hewlett Packard Labs, Bristol, UK; 14 males. Frequent computer users with no prior knowledge of seminar subject matter.
Study design:		Between-subjects.
Presence measures:		6-item SUS Presence Questionnaire (slightly modified).
Person-related meas.:		Game playing experience.
Task-related measures:		Kennedy SSQ, *confidence ratings and memory awareness states (guess, familiar, remember*, *know) included with memory recall and spatial awareness questionnaire*.
Performance measures:		22-item memory recall, *Spatial Awareness Questionnaire*.
Findings:	(1)	Environment type had a significant effect on presence overall and for all questions except 1 (images seen or heard compared with place visited), with higher presence reported for real condition than for the other 3 conditions. No significant difference in presence between the desktop, HMD, or audio-only conditions.
	(2)	Game-playing experience had no significant correlation with presence.
	(3)	Total SSQ score had no significant correlation with presence in the HMD condition.
	(4)	Memory recall had no significant correlation with presence.
	(5)	*Environment type had a significant effect on memory recall, with increased recall in the real condition compared with the HMD and audio-only conditions, but three was no significant difference between real and desktop environments or between audio-only, HMD, and desktop conditions.*
	(6)	*For memory recall, environment type had a significant effect on confidence ratings, with increased confidence reported for the real condition than for the desktop condition, for the desktop condition than for the HMD condition, and for the audio-only conditions than for the HMD condition.*
	(7)	*For memory recall, environment type had a significant effect on memory awareness states, with more “guesses” made for HMD than for either real or audio-only conditions only. Also, a significantly higher probability that “guess” responses were correct for real, HMD, and audio-only conditions than for desktop condition.*
	(8)	*Visual stimulation had a significant positive effect on memory recall performance, with better performance for questions that had answers written on slides and communicated aurally for the desktop than for audio-only condition.*
	(9)	*Environment type had no significant effect on spatial awareness.*
	(10)	*For spatial awareness, environment type had no significant effect on confidence ratings.*
	(11)	*For spatial awareness, environment type had a significant effect on memory awareness states, with the probability of “remember” responses being correct higher for HMD compared with real conditions but not desktop and the probability of “familiar” responses being correct higher for the real compared with HMD conditions.*

[Mania 2001b] Mania, K. 2001. “Connections Between Lighting Impressions and Presence in Real and Virtual Reality.” In *Proc. 1st Inter. Conference on Computer Graphics, Virtual Reality, Visualization, and Interaction* in Africa (AFRIGRAPH). Capetown, South Africa. 119–123.

Factors:		Environment type (real, HMD stereo, HMD mono head-tracked, HMD mono mouse, desktop monitor).
Computing platform:		VE created using 3-D Studio MAX modeling suite and Lightscape radiosity software.
Visual display:		In real-world condition, goggles used to restrict FOV to same across all conditions. Resolution same across VE conditions. Photorealistic representation.
Tracking:		Head-tracking for some conditions.
Navigation:		None.
Object manipulation:		None.
Virtual world:		4×4 m room. Viewpoint set in middle of room, with full horizontal rotation and 180° vertical rotation.
Experimental task:		Spatial task. 3-min. exposure to virtual world.
Participants:		105 undergraduate and M.Sc. students.
Study design:		Between-subjects.
Presence measures:		6-item SUS Questionnaire.
Task-related measures:		Quality of Lighting Questionnaire.
Findings:	(1)	Environment type had no significant effect on presence.
	(2)	Quality of lighting had a significant negative correlation with presence.
	(3)	*Environment type had no significant effect on ratings of quality of lighting*.

[Mania 2000] Mania, K. and A. Chalmers. 2000. *A User-Centered Methodology for Investigation Presence and Task Performance.* Presented at PRESENCE 2000: The 3rd International Workshop on Presence, 27–28 March, Delft, The Netherlands.

Factors:		Environment type (real, virtual with audio, audio only).
Computing platform:		PC with hardware accelerator. In-house Virtual Reality Modeling Language (VRML) and Java software.
Visual display:		21-in. monitor. Frame rate 40 fps.
Navigation:		For visual conditions, using standard mouse to explore room from a steady view-point, approximately placed in center of room, with ability to move in a full circle, as well as emulating head movement.
Object manipulation:		None.
Virtual world:		Model of a university seminar room using static billboard with texture to display lecturer and slide show to present 12 “overhead” slides. Slides synchronized with audio taken from digital video recording of real condition.
Experimental task:		Attend a seminar in form of a 15-min. lecture (included 12 slides shown on an overhead projector in real condition).
Participants:		3 groups of 18 participants.
Study design:		Between-subjects.
Presence measures:		6-item SUS Questionnaire.
Performance measures:		16-item Knowledge Acquisition Questionnaire and 6-item Environment Perception Questionnaire (latter part not used in audio-only condition).
Findings:	(1)	Environment type had a significant effect on presence, with more presence reported for the real condition than for either the virtual or audio-only condition, but there was no significant difference between the virtual and audio-only conditions.
	(2)	Task performance had no significant correlation with presence.

(3) *Environment type had a significant effect on task performance, with improved performance found for real and audio-only conditions but no significant difference for virtual with audio condition.*
(4) *Visual stimulation had a significant positive effect on task performance, with better performance for questions with answers written on slides and mentioned by lecturer for real and virtual conditions as compared with audio-only condition.*

[McLaughlin 2003] McLaughlin, M., G. Sukhatme, W. Peng, W. Zhu, and J. Parks. 2003. "Performance and Co-Presence in Heterogeneous Haptic Collaboration." In *Proc. 11th International Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems (HAPTICS 2003)*, 22–23 March, Los Angeles, CA.

Visual display: Desktop monitors.
Haptic display: PHANTOM, CyberGrasp glove.
Experimental task: PHANTOM used to communicate information to partner through a tactile "Morse code" that maps the number of times a particular digit is touched onto letters of the alphabet. A keyboard showing this mapping is visible on his display. The participant using the CyberGrasp glove holds his hand stationary during transmission and then enters the letters received onto keyboard visible is his display. Nine 3- and 2-letter words to transmit.
Participants: 12 participants, working in pairs.
Presence measures: 8-item Co-presence Questionnaire.
Task-related measures: Mean force applied, *rating of perception of partner*.
Performance measures: Task accuracy, task completion time.
Findings:
(1) Co-presence had no significant correlation with task accuracy.
(2) Co-presence had a significant negative correlation with mean force applied.
(3) *Task completion time had a significant negative correlation with accuracy.*
(4) *Mean force applied had no significant correlation with accuracy*.

[Meehan 2003] Meehan, M., S. Razzaque, M.C. Whitton, and F.P. Brooks, Jr. 2003. "Effect of Latency on Presence in Stressful Virtual Environments." In *Proc. IEEE Virtual Reality 2003 Conference*, 22–26 March, Los Angeles, CA. 141–148.

Factors: End-to-end latency (~ 50 ms, ~ 90 ms).
Computing platform: 1.8-GHz Pentium IV PC with a dual NVIDIA GeForce Ti 4600 graphics card and Creative Labs Audigy sound card. Modified WildMagic software game engine. Additional PCs for data recording and viewing.
Visual Display: Virtual Research V8 HMD with 640 × 480 resolution for each eye, 60° diagonal FOV, refresh rate 60 Hz. IPD-adjusted for each participant.
Audio display: Sennahesier HD 250 II sealed circumaural headphones replaced standard HMD headphones to provide spatialized background music coming from a virtual radio and instructions from a virtual wall-mounted speaker.
Haptic display: Passive haptics using a real 1.5-in. wooden ledge, walls, and counters. Fan (and moving curtains) to simulate wind.
Tacking: 3rdTech, Inc. HiBall 3000 tracker for head and hand position.
Physiological devices: Thought Technologies Ltd. ProComp+ Tethered Telemetry system, sampling skin conductance at 32 Hz and electrocardiogram (EKG) at 256 Hz. Essilor Digital Corneal Reflex Pupillometer (CRP) for measuring participant IPD.
Virtual world: Slater's virtual pit environment consisting of a training room and door leading to a 2-story tall pit room with 2-ft. ledge around a 20-ft. chasm.
Training: 5 min. used to familiarize participants with hardware devices and cable management. In practice VE room, responded to instructions to navigate around the room and pick up and drop bean bags.

Experimental task:		Following recorded instructions, enter Pit Room, test a real 1.5-in. wooden ledge with their feet and drop two beanbags onto the target areas in the chasm.
Participants:		164 SIGGRAPH 2002 conference participants; 132 males; mean age 35.
Study design:		Between-subjects.
Presence measures:		Shortened version of UCL Questionnaire, with 1 item to rate amount of fear experienced and 5 presence items based on SUS Questionnaire with values of "5," "6," and "7" used for high presence rating, Δheart rate (data available for only 61 participants), Δskin conductance (data available for only 67 participants).
Task-related measures:		Kennedy SSQ, *self-reported fear*.
Findings:	(1)	Latency had no significant effect on presence and fear measured using the UCL questionnaire.
	(2)	Latency had a significant effect on Δheart rate, with greater presence reported for the lower latency (when the SSQ Nausea subscale was taken into account).
	(3)	Latency had no significant effect on Δskin conductance.
	(4)	SSQ Nausea subscale had a significant positive correlation with both Δheart rate and Δskin conductance.
	(5)	*Reported fear had a significant positive correlation with SSQ Total score and Nausea, Ocular Discomfort, and Disorientation subscales*.

[Meehan 2001 (1)] Meehan, M. March 2001. *Physiological Reactions as an Objective Measure of Presence*. Ph.D. Dissertation. University of North Carolina at Chapel Hill, NC.

Factors:		Multiple exposures (2 to 12).
Computing platform:		SGI Reality Monster, using 1 Infinite Reality 2 pipe. In-house software.
Visual display:		Virtual Research V8 HMD, with 640 × 480 tri-color pixel resolution per eye. Update rate generally 30 fps.
Haptic display:		Real 1.5-in. high plywood ledge registered with virtual ledge over chasm.
Tracking:		Large-area optical tracking system using UNC Tech Hi-Ball, allowing movement in 4 × 10 m area. Movement lag ~ 100 msec.
Navigation:		Actual walking.
Object manipulation:		Hand control with push buttons.
Virtual world:		Pit room entered from training room. In the pit room, a 20-ft. chasm surrounded by a 2-ft. walkway, with a ledge extending over the chasm. Area 18 × 32 ft. VE ranged from 10,000–20,000 polygons, with 41–50 MB texture mapping. Self-representation as virtual body.
Training:		Training room where users learn to navigate and pick up and move a virtual book. Approximately 2 min.
Experimental task:		Carry a virtual book into the pit room and place on a chair on the far side of the pit from the entrance. Typically took 40 sec.
Participants:		10 participants; 3 males; mean age 24.4 yr. Three or fewer prior experiences of immersive VEs.
Study design:		Within-subjects.
Presence measures:		Δskin conductance level, Δskin temperature, UCL questionnaire. Observed behavioral measures: count of behaviors believed to be associated with moving about near a real 20-ft. drop, such as slower motion, leaning against wall, testing edge with foot, and vocal exclamation.
Task-related measures:		Kennedy SSQ.
Findings:	(1)	Repeated exposures had a significant negative effect on Δskin temperature and reported behavioral presence after the first exposure only and on observed behavioral presence on subsequent days. It had a significant positive effect on Δskin conductance. No significant effect on other presence measures.
	(2)	Δskin conductance, Δskin temperature, and observed behavioral presence had no significant correlation with either reported presence or reported behavioral presence.

[Meehan 2001 (2)] Meehan, M. March 2001. *Physiological Reactions as an Objective Measure of Presence*. Ph.D. Dissertation. University of North Carolina at Chapel Hill, NC.

Factors:	Haptic cues (mixed reality wooden ledge, virtual ledge only).
Computing platform:	Virtual world: As in [Meehan 2001 (1)].
Training:	As in [Meehan 2001 (1)], but included viewing pit room from doorway.
Experimental task:	Carry a virtual book into the pit room and to the end of a wooden diving board, count to 10, and look around. Then carry book to a chair on the far side of the pit from the entrance. Pit surrounded by a narrow ledge. Typically took 90 sec.
Participants:	52 participants; 36 males; mean age 21.4 yr. Three or fewer prior experiences of immersive VEs.
Study design:	Within-subjects.
Presence measures:	As in [Meehan 2001 (1)], with Δheart rate added.
Task-related measures:	As in [Meehan 2001 (1)].
Findings: (1)	Haptic cues had a significant positive effect on Δheart rate, Δskin conductance, observed behavior, and reported behavioral presence but had no significant effect on reported presence or Δskin temperature.
(2)	Δheart rate, Δskin conductance, and Δskin temperature had no significant correlation with either reported presence or reported behavioral presence. Observed behavioral presence had no significant correlation with reported presence but had a significant positive correlation with reported behavioral presence.
(3)	Repeated exposures had a significant negative effect on reported presence and reported behavioral presence after the first exposure only. No significant effect for other presence measures.

[Meehan 2001 (3)] Meehan, M. March 2001. *Physiological Reactions as an Objective Measure of Presence*. Ph.D. Dissertation. University of North Carolina at Chapel Hill, NC.

Factors:	Frame rate (30, 20, 15, 10 fps).
Computing platform:	Training: As [Meehan 2001 (1)].
Experimental task:	Carry a virtual block into the pit room and drop it over a spot marked on floor of pit and then grab additional blocks floating in the air drop those at other locations marked on the pit floor. Typically took 90 sec.
Participants:	33 participants; 25 males; mean age 22.3. Three or fewer prior experiences of immersive VEs.
Study design:	Within-subjects.
Presence measures:	As in [Meehan 2001 (1)].
Task-related measures:	As in [Meehan 2001 (1)].
Findings: (1)	Frame rate had a significant effect on Δheart rate, Δskin conductance, Δskin temperature, reported behavioral presence only (part of UCL questionnaire), and observed behavioral presence, with more presence reported for 30 and 20 fps.
(2)	Δheart rate, Δskin conductance, Δskin temperature, and observed behavioral presence had no significant correlation with either reported presence or reported behavioral presence.
(3)	Observed behavioral presence had no significant correlation with reported presence but had a significant positive correlation with reported behavioral presence.
(4)	Repeated exposures had a significant negative effect on Δskin conductance, Δskin temperature, and observed behavioral presence after first exposure only and on Δheart rate and reported behavioral presence over exposures on the same day. No significant effect on reported presence.

[Nichols 2000 (1)] Nichols, S., C. Haldane, and J.R. Wilson. 2000. "Measurement of Presence and Its Consequences in Virtual Environments." *Inter. Journal of Human-Computer Studies*, 52, 471–491.

Factor:		Visual display (HMD, desktop), audio cues (present, absent).
Computing platform:		Pentium 133 PC, with Superscape Voice Recognition Technology (VRT) software. Frame rate ~ 10 fps, with tracker delay of 4 ms.
Visual display:		I-glasses HMD.
Audio display:		Headphones embedded in HMD.
Navigation:		Using head movements to alter viewpoint.
Object manipulation:		Using 3-D mouse.
Virtual world:		"Duck shoot" fairground stall. Percentage accuracy and number of ducks shot displayed on the screen. Participants given an incentive to perform well by being told a financial bonus would go to the top 5 high scorers. Startle event occurred between 5 and 6 min. and consisted of a duck that had been hit zooming out into the foreground and "exploding." Nondirectional sound cues consisted of continual duck quacking noises, with a special quack when shot.
Experimental task:		Play fairground game. 10-min. time limit.
Participants:		24 undergraduate students; 12 males; age range 18 to 25. No prior experience of VEs.
Study design:		Within-subjects for type of visual display; between-subjects for audio cues.
Presence measures:		Reaction to a randomly timed "startle event," recall of different types of background music played in the lab that were out of context with the virtual world, and questionnaire.
Task-related measures:		*Short Symptom Checklist (SSC) for simulator sickness.*
Findings:	(1)	Visual display had a significant effect on reflex response presence, with greater response found for the HMD but no significant difference for background awareness presence measure. For the questionnaire, type of visual display had a significant effect on "being" and "visit" presence items only.
	(2)	Audio cues had a significant positive effect on reflex response presence measure for HMD users but had no significant effect on background awareness presence measure. For the questionnaire, audio cues had no significant effect on presence items.
	(3)	*For HMD condition, total SSC scores had no significant correlation with any presence measure.*

[Nichols 2000 (2)] Nichols, S., C. Haldane, and J.R. Wilson. 2000. "Measurement of Presence and Its Consequences in Virtual Environments." *Inter. Journal of Human-Computer Studies*, 52, 471–491.

Computing platform:		Division, Ltd. Provision 100 VPX. Frame rate range 2–15 fps, with 20-ms lag.
Visual display:		Division, Ltd. HMD.
Navigation:		Using head movements to alter viewpoint.
Object manipulation:		Using 3-D mouse.
Virtual world:		Virtual house.
Experimental task:		Explore rooms in house and perform specified tasks in each room. (Tasks designed to ensure a range of physical movements, and both gross and small manipulation using hand-held 3-D mouse.) Tasks included a 3-D jigsaw puzzle, estimating reach distance and picking up pencils. 20-min. time limit.
Participants:		20 participants; 10 males; age range 18 to 41; mean age 24.5 yr.
Presence measures:		Witmer-Singer PQ.
Task-related measures:		Kennedy's SSQ, Adjectival Response Scale (ARS) measure of enjoyment, *SSC.*
Findings:	(1)	PQ Interface subscale had a significant negative correlation with post-participation levels on SSQ Total and all subscales.

(2) PQ Interface subscale had a significant positive correlation with reports of a positive experience. PQ Total and Involved/Control subscale each had a significant positive correlation with overall enjoyment.

[Nicovich 2005] Nicovich, S.G., G.W. Boller, and T.B. Cornwell. 2005. "Experienced Presence Within Computer-Mediated Communications: Initial Explorations on the Effects of Gender With Respect to Empathy and Immersion." *Journal of Computer-Mediated Communication*, 10(2), Article 6.

Factors:	Interactivity (present, absent), vividness (high, low).
Computing platform:	Microsoft Flight Simulator 98.
Visual display:	Desktop monitor.
Auditory display:	PC speakers.
Tracking:	None.
Navigation:	Using joystick.
Object manipulation:	Using joystick.
Virtual world:	As in game. High-vividness condition included high resolution and sound; low-vividness condition used lower resolution and no sound.
Training:	Instruction on how to use the game controls and the meaning of readouts. Practice with game until demonstrated a level of comfort with the plane and joystick controls.
Experimental task:	Participants in interactive condition given a take-off and landing task, 10 min. allowed. Participants in the no interactivity condition watched a prerecorded video of the same game scenario.
Participants:	184 graduate and undergraduate students; 89 males; age range 18 to 54.
Study design:	Between-subjects.
Presence measures:	5-item questionnaire.
Person-related meas.:	Gender.
Task-related measures:	5-item Empathy Questionnaire.

Findings:

(1) Interactivity had a significant effect on presence, with participants in the interactive conditions reporting more presence.

(2) Vividness had a significant effect on presence, with participants in the high condition reporting more presence.

(3) In the interactive condition, empathy had no significant correlation with presence.

(4) In the high-vividness condition, gender had no significant effect on presence.

(5) In the interactive condition, gender had a significant effect on presence, with males reporting significantly less presence than women in the noninteractive condition and significantly more presence than women in the interactive condition.

(6) The interaction of gender and interactivity had a significant effect on presence, with males reporting more presence in the interactive conditions than in the non-interactive condition.

[Noel 2004] Noel, S., S. Dumoulin, T. Whalen, M. Ward, J. Stewart, and E. Lee. 2004. "A Breeze Enhances Presence in a Virtual Environment." In *Proc. 3rd IEEE International Workshop on Haptic Audio Visual Environments and Their Applications*. 2–3 October, Ottawa, Ontario, Canada. 63–68.

Factors:	Haptic feedback (self-generated breeze, object-generated breeze, natural breeze, no breeze).
Computing platform:	Pentium III with dual 1-GHz processors, nVidia GeForce III video card. Software used VRML97 markup with FreeWRL VRML browser. Frame rate ~ 25 fps. Breeze generated.
Visual display:	Virtual Research V8 HMD.
Haptic display:	Breeze cannon constructed from a bathroom ventilation fan blowing 110 cu. ft. of air through a 3–in. diameter nozzle. Fan ran continuously and was manually controlled to 1 of 3 levels: no breeze, weak breeze, strong breeze. Nozzle placed 60 cm

	from participant's face. Self-generated breeze caused breeze cannon to be activated whenever the participant moved through the virtual world, with speed determining breeze strength. An object-generated breeze was synchronized with the movement of the virtual airplanes in front of the participant's avatar. In the natural breeze condition, a breeze was provided for ~ 10 sec. in every minute.
Tracking:	Head-tracking using Polhemus 6 DOF motion tracker mounted on chair.
Navigation:	Computer joystick.
Object manipulation:	None.
Virtual world:	Urban park with ~ 300 widely spaced, simple pine trees, 4 differently colored houses randomly placed (one in each quadrant) and a fifth house near the center of world. Each house had a colored beacon on its room that lit up when that house was the next to be visited. Each house turned white when participant got near to it. Each quadrant had a different backdrop: urban skyline, mountain chain, wheat field, moor. Six objects represented radio-controlled airplanes (one circling around each house) and the sixth followed a circular trajectory around the participant. Forest sounds, including bird songs, played in a continuous loop at a low level to block background noises.
Training:	Training in using the joystick, ~ 1 min. and then practice trial with houses also marked with a colored pole on each roof.
Experimental task:	Guided by the order in which beacons lit up, visit each house in turn as quickly as possible. 4 trials (with presence questionnaire delivered after each).
Participants:	8 participants; 3 males; age range 26 to 48; mean age 35 yr.
Study design:	Within-subject.
Presence measures:	4-item version of Prothero's Presence Questionnaire.
Task-related measures:	Kennedy's SSQ, Awareness and Ratings of Breeze Questionnaire (completed at end of last trial).
Performance measures:	*Time to complete*.
Findings: (1)	Haptic feedback had a significant effect only on the first presence item (whether felt in lab or VE), with more presence reported for the self-generated breeze condition than for the object-generated and no breeze conditions.
(2)	*Haptic feedback had no significant effect on time to complete the task.*

[Nowak 2003] Nowak, K.L. and F. Biocca. 2003. "The Effect of Agency and Anthropomorphism on Users' Sense of Telepresence, Co-presence, and Social Presence in Virtual Environments." *Presence*, 12(5), 481–494.

Factors:	Anthropomorphism (high, low, no image), perceived agency (told human-controlled avatar, told computer-controlled avatar).
Visual display:	19-in. desktop monitor.
Auditory display:	Headphones and microphone.
Tracking:	None.
Navigation:	None.
Object manipulation:	None.
Virtual world:	Meeting room with a sign indicating that participants were in a scavenger hunt meeting place. Virtual partner represented by a female virtual face, abstract face, or no image; participant selection of face used when image provided.
Experimental task:	Participants were told either that they were interacting with a computer-controlled agent or a human-controlled avatar. They had to get to know their partner with whom they may work in the future on a scavenger hunt. All partner responses using a pre-recorded female voice reading from a script. Average interaction lasted about 15 min.
Participants:	134 undergraduates; 94 males; age range 19 to 33; mean age 21 yr.
Study design:	Between-subjects.

Presence measures:		5-item presence questionnaire, 12-item Perceived Other's Co-Presence Questionnaire, 6-item Self-Reported Co-Presence Questionnaire, 6-item Social Presence Questionnaire.
Findings:	(1)	Perceived agency had no significant effect on presence, perceived other's co-presence, self-reported co-presence, or social presence.
	(2)	Anthropomorphism had no significant effect on presence but had a significant interaction effect with agency such that more presence was reported when a partner was represented by an image and those in the low-anthropomorphism group reported significantly less presence than those in the high-anthropomorphism group.
	(3)	Anthropomorphism had a significant effect on co-presence, with low-anthropomorphism participants reporting more perceived other's co-presence, self-reported co-presence, and social presence than those in the other groups.
	(4)	Perceived other's co-presence had a significant positive correlation with presence and social presence.
	(5)	Self-reported co-presence had a significant positive correlation with presence and social presence.
	(6)	Social presence had a significant positive correlation with presence, perceived other's co-presence, and self-reported co-presence.

[Nuñez 2003a] Nuñez, D. and E. Blake. 2003a. "A Direct Comparison of Presence Levels in Text-Based and Graphics-Based Virtual Environments." In *Proc. 2nd International Conference on Computer Graphics, Virtual Reality, Visualization, and Interaction in Africa*, Cape Town, South Africa. 53–56.

Factors:		Visual and auditory quality (high, low, text).
Visual display:		High quality graphics version rendered at 640 × 480 × 16 resolution, including textures, radiosity, and sound, with refresh rate 17 Hz.
Audio display:		Stereo headphones.
Navigation:		For high- and low-quality graphics and sound versions, quake keys navigation method using mouse to change view yaw and pitch and keyboard for achieving walking motion. For text version, using key commands from menus.
Object manipulation:		None.
Virtual world:		Medieval monastery. Graphics/sound versions rendered at 640 × 480 × 16 resolution. Two versions contained containing 18 furnished rooms over 3 levels, connected by 2 stairways, included textures, radiosity, and sound. The low-quality version used flat, shaded polygons and no sound. Text version contained 27 rooms (counting long passageways and stairways), 20 of which had a text descriptions accompanied by a 280 × 100 × 8 resolution still image. Text descriptions only included information available in the graphics/sound versions.
Training:		Practice with system, in a different virtual world, for 5 min.
Experimental task:		Explore monastery, locating 20 boxes positioned throughout the building. 15 min. allowed.
Participants:		78 students, mostly first-year science students.
Study design:		Between-subjects.
Presence measures:		6-item SUS Questionnaire, Witmer-Singer PQ.
Findings:	(1)	Visual and auditory quality had a significant effect on SUS scores, with participants in the high condition reporting more presence than participants in the low or text conditions.
	(2)	Visual and auditory quality had a significant effect on PQ scores, with participants in the high condition reporting more presence than participants in the low or text conditions and participants in the low condition reporting more presence than those in the text condition.

[Nuñez 2003b] Nuñez, D. and E. Blake. 2003b. "The Thematic Baseline Technique as a Means of Improving the Sensitivity of Presence Self-Report Scales." Presented at the 6th International Workshop on Presence. 6–8 October, Aalborg, Denmark.

Factor:		Visual and auditory quality (high, low), priming (related materials, unrelated materials).
Computing platform:		AMD Athlon 700 MHz PC, with GeForce 2 MX graphic card. DAVE software system.
Visual display:		17-in. desktop monitor for presentation of stereo sound.
Audio display:		Stereo headphones.
Navigation:		Quake keys navigation method using mouse to change view yaw and pitch, and keyboard for achieving walking motion.
Object manipulation:		None.
Virtual world:		One virtual world was a medieval monastery consisting of 16 rooms over 3 levels; the second was a contemporary hospital with 15 rooms over 4 levels.
Training:		Third virtual building used for training, consisting of 12 rooms spread over 3 levels. The high-quality versions used textures, radiosity, and 3-D sound. The low-quality versions used flat, shaded polygons and no sound.
Experimental task:		After reading priming material, explore virtual world. 15 min. allowed. 1 trial in each of 2 virtual worlds, with presence data collected after each.
Study design:		Between-subjects.
Participants:		55 undergraduate students; in early 20s.
Presence measures:		Witmer-Singer PQ, SUS Questionnaire.
Findings:	(1)	Visual and auditory quality had a significant effect on presence as measured using both the PQ and the SUS Questionnaire, with more presence reported for the high visual and auditory quality.
	(2)	Priming had no significant effect on either presence measure. There was a significant interaction with visual and auditory quality such that there was a difference for visual and auditory stimulus only when participants were primed with related materials.

[Nystad 2004] Nystad, E. and A. Sebok. 2004. "A Comparison of Two Presence Measures Based on Experimental Results." Accepted for 7th Annual International Workshop on Presence, 13–15 October, Valencia, Spain.

Factor:	Visual display (HMD with head-tracking, large screen with stereo, desktop display with stereo, desktop display).
Computing platform:	VRTexp training application developed using extended version of XJ3-D.
Visual display:	HMD, desktop monitor.
Tracking:	Head-tracking for HMD.
Navigation:	Using mouse.
Object manipulation:	Using mouse.
Virtual world:	Representation of a nuclear reactor hall.
Training:	10-min. practice scenario to gain familiarity with navigating and selecting objects.
Experimental task:	Learn an 8- to-12-step control-station change-out maintenance procedure in a nuclear reactor setting. Four 30- to 60-min. training sessions, each starting with passive viewing before active performance.
Participants:	24 employees at the Organisation for Economic Co-operation and Development (OECD) Halden Reactor Project (HRP); 22 males; age range 25–61.
Study design:	Between-subject, with each participant using 3 of the 4 visual display types. Half of the participants responded using PQ and half using SUS Questionnaire.
Presence measures:	Witmer-Singer PQ, SUS Questionnaire.

Person-related meas.:		Rating of familiarity with the real reactor hall depicted in the VE, Witmer-Singer ITQ.
Task-related measures:		Brooks 10-item Usability Questionnaire.
Performance measures:		Number of incorrect actions during training, recall of procedural steps and tools used while looking at pictures of reactor hall for retention test taken 1 day later.
Findings:	(1)	Visual display had no significant effect on presence as measured using either the PQ or SUS Questionnaire.
	(2)	Usability had a significant positive correlation with PQ (Total) and PQ Involved Control and PQ Interface Quality subscales but had no relationship with SUS Questionnaire.
	(3)	Errors during training had a significant negative correlation with SUS Questionnaire only in 3rd active repetition. No correlation with PQ.
	(4)	Retention test results showed a significant negative correlation between error tool count and the SUS Questionnaire and a significant positive correlation with PQ Interface Quality subscale. No relationship for procedural errors.
	(5)	Familiarity with the environment had a significant positive correlation with SUS Questionnaire but not with PQ.
	(6)	ITQ (Total) and ITQ Involvement subscale had a significant positive correlation with the SUS Questionnaire. ITQ (Total) and ITQ Focus subscale had a significant negative correlation with the PQ Natural subscale.

[Olsson 2001] Olsson, M., K. Vien, E. Ng, R. So, and H. Alm. 2001. "Effects of Vection on the Sense of Presence in a Virtual Environment." In *Proc. HCI International 2001*, 5–10 August, New Orleans, LA.

Factors:		Vection (present, absent).
Computing platform:		SGI Onyx II station. Simulation generated using Sense8 Corp. WorldToolKit Release 8.
Visual display:		Virtual Reality Corp. VR4 HMD.
Tracking:		Head and hand tracking using Polhemus 3Space Fastrack.
Object manipulation:		Using cyberglove.
Virtual world:		Acoustic room, 4.8 × 11.7 m, with table in front of participant. Virtual monitor, speakers, push buttons, cubes, and cylinders on table. In condition with vection, at 5, 12, 19, and 26 min., perform virtual navigation tour in the fore-and-aft and lateral directions around the room. Speed of travel 1 m/sec., duration of tour 2 min. Navigation tour combined with visual search tasks. Visual search task requiring same head movements performed by participants in nonvection condition. 30 min.
Training:		Guided viewing of virtual room. 2 min.
Experimental task:		Perform series of sound localization, visual search, and object manipulation tasks.
Participants:		24 students; 12 males; age range 20 to 24 yr.
Study design:		Between-subjects.
Presence measures:		Presence questionnaire, modified 5-item SUS Questionnaire.
Person-related meas.:		*Motion Sickness Susceptibility Survey (MSSS), ITQ.*
Task-related measures:		*Kennedy SSQ. 7-point nausea rating, vection rating taken after each navigation tour.*
Findings:	(1)	Vection had no significant impact on presence questionnaire or SUS scores.
	(2)	SUS scores had a significant positive correlation with presence questionnaire Involvement/Control, Natural, and Haptic subscale scores and with PQ Total scores.

[Petzold 2004] Petzold, B., M.F. Zaeh, B. Faerber, B. Demi, H. Egermeier, J. Schilp, and S. Clarke. 2004. "A Study on Visual, Auditory, and Haptic Feedback for Assembly Tasks." *Presence*, 13(1), 16–21.

Factors:		Haptic force feedback (delivered to fingertip, none), audio feedback (sound of collisions, absent), visual force feedback (bar graph of force strength/direction, absent).
Computing platform:		Virtual Engineering Environment Ve^2 (based on Sense8 Corp. WorldToolKit) for visual rendering, Solid 3.1 for collision detection.
Visual display:		Desktop monitor.
Tracking:		None.
Navigation:		None.
Object manipulation:		SensAble Technologies PHANTOM force feedback device.
Virtual world:		Representation of a flat surface with a gear shaft mounted on a virtual fixture, gear wheel also shown.
Training:		Learning how to use the PHANTOM, then one task trial.
Experimental task:		Mount a gear wheel on a gear shaft as fast as possible.
Participants:		48 participants.
Study design:		Between-subjects.
Presence measures:		Presence questionnaire with subscales Spatial presence, Quality of interface, Emotional involvement.
Performance meas.:		Task completion time.
Findings:	(1)	Haptic force feedback had a significant effect on presence, with more presence reported when haptic force feedback was present.
	(2)	Audio feedback had no significant effect on presence.
	(3)	Visual feedback on forces exerted had no significant effect on presence.
	(4)	Task completion time had a significant negative correlation with total presence scores.
	(5)	*Haptic force feedback, audio feedback, and visual force feedback each had no effect on task completion time.*

[Preston 1998] Preston, L. November 1998. *The Use of Virtual Reality in the Reduction of Stress*. Honours thesis. Rhodes University, South Africa.

Factor:		Level of interaction (interaction with VE, watching video through HMD).
Computing platform:		SGI O2. RhoVeR software system with CoRgi Toolkit.
Visual display:		General Reality CyberEye HMD. Frame rate 6–8 fps. Participants seated in a swivel chair positioned in a darkened room.
Audio display:		HMD headphones.
Tracking:		Polhemus InsideTrak for head and hand tracking.
Navigation:		Using a handheld stick with 4 switches to control movement.
Object manipulation:		Using the handheld stick, click switches to move fingers on virtual hand.
Virtual world:		Derived from SGI's underwater demo environment where participant can interact with a range of marine mammals, modified so that dolphins show curiosity about the diver and spend a portion of their time in the diver's vicinity. Participants swim around, touch a dolphin or swaying sea plant, and ride a dolphin. Images constructed from smoothed and shaded polyhedral objects with texture mapping. Musical background. Self-representation as virtual hand.
Experimental task:		Swim with dolphins. 5-min. time limit.
Participants:		35 university students; 23 males; 4 participants between 10 and 20 yr., 31 participants between 21 and 30 yr.
Study design:		Within-subjects.
Presence measures:		Δheart rate. Also 1-item presence questionnaire.
Finding:	(1)	Level of interaction had no significant effect on Δheart rate.

[Priore 2003] Priore, C.L., G. Castelnuovo, D. Liccione, and D. Liccione. 2003. "Experience with V-STORE: Considerations on Presence in Virtual Environments for Effective Neuropsychological Rehabilitation of Executive Functions." *CyberPsychology & Behavior*, 6(3), 281–287.

Factors:		Type of visual display (HMD, desktop monitor).
Computing platform:		V-Store system for cognitive (executive function) rehabilitation.
Visual display:		HMD, desktop monitor.
Audio display:		Stereo speakers.
Tracking:		3 DOF tracking device for head-tracking with HMD.
Navigation:		Joystick.
Object manipulation:		Joystick buttons for picking up/dropping objects.
Virtual world:		Inside of a goods store.
Training:		8-min. practice with V-Store environment, objects, and commands.
Experimental task:		Two series of tasks ordered in ascending level of difficulty. Participant explores a goods store to solve a series of tasks, such as putting pieces of fruit into a basket according to an imparted disposition. Distracting elements used to generate time pressure and elicit managing strategies. Radio broadcast presented over audio speakers. Each series of tasks took 8 min.
Participants:		12 participants. No reported neurological or psychiatric problems.
Study design:		Between-subjects.
Presence measures:		ITC-SOPI questionnaire, Δskin conductance [Galvanic Skin Reflex (GSR) recorded using Psycholab VD13], BIPs, incidental memory (assessed using answers to questions on radio broadcast).
Findings:	(1)	Type of visual display had a significant effect on Δskin conductance, with higher values obtained with the HMD. Task difficulty had no significant effect on Δskin conductance.
	(2)	Type of visual display had a significant effect only on ITC-SOPI Negative Effects factor, with participants using the HMD reporting more negative effects.
	(3)	Type of visual display had no significant effect on presence as assessed by the incidental memory and BIP measures.

[Prothero 1995a (1)] Prothero, J.D., H.G. Hoffman, D.E. Parker, T.A. Furness III, and M.J. Wells. 1995. "Foreground/Background Manipulations Affect Presence." In *Proc. Human Factors and Ergonomics Society 39th Annual Meeting*, San Diego, CA. 1410–1414.

Factors:	Visual scene (as foreground, as background).
Computing platform:	Division, Ltd. ProVision 100 system.
Visual display:	Division, Ltd. dVisor HMD with 40° V × 105° H, 40° overlap. Eye mask provided by Lucas Products Corp. Super Sunnies tanning goggles with central ultraviolet (UV) protectors removed, providing FOV 40° direct, 60° peripheral, or screen mask provided by paper mask mounted on HMD screens with 2.54-cm diameter holes providing FOV 60°.
Object manipulation:	Virtual net slaved to real hand position.
Virtual world:	Division Ltd. SharkWorld: a texture mapped underwater scene with a sunken ship and various moving sea creatures.
Experimental task:	Catch sharks using a virtual net. 2.5-min. time limit.
Participants:	26 adults; 19 males. 3 participants reported more than 10-min. prior VE experience.
Study design:	Within-subjects.
Presence measures:	Questionnaire.

Findings:	(1)	Visual scene manipulation had a significant effect on overall presence score and each item separately, with more presence reported when virtual scene was perceived as background.
	(2)	Order had a significant effect such that the difference between conditions was significant only when the eye mask was used first.

[Prothero 1995a (2)] Prothero, J.D., H.G. Hoffman, D.E. Parker, T.A. Furness III, and M.J. Wells. 1995. "Foreground/Background Manipulations Affect Presence." In *Proc. Human Factors and Ergonomics Society 39th Annual Meeting*, San Diego, CA. 1410–1414.

Factors…		
Presence measures:		As in [Prothero 1995a (1)], except for participants: 13 adults; 9 males. One participant reported more than 10-min. prior experience. Conducted as double-blind experiment.
Findings:	(1)	Visual perimeter had a significant effect on overall presence score, with more presence reported when virtual scene was perceived as background.

[Prothero 1995b] Prothero, J.D. and H.G. Hoffman. 1995. *Widening the Field-of-View Increases the Sense of Presence in Immersive Virtual Environments*. Available at http://www.hitl.washington.edu/publications/r-95-5/.

Factors:		FOV [unrestricted 40° V × 105° H, restricted (direct 40°, peripheral 60°)].
Computing platform:		Division, Ltd. ProVision 100 system.
Visual display:		Division, Ltd. dVisor HMD with 40° V × 105° H, 40° overlap. Eye mask provided by Lucas Products Corp. Super Sunnies tanning goggles with central UV protectors removed.
Tracking…		
Experimental task:		As in [Prothero 1995a (1)].
Participants:		38 high school students; 20 males; age range 16–18. No participants reported more than 10-min. prior experience.
Study design:		Within-subjects.
Presence measures:		5-item presence questionnaire.
Person-related meas.:		Gender.
Findings:	(1)	FOV had a significant effect on overall presence score, with increased presence reported for unrestricted FOV. When analyzed separately, a significant difference was found for only 2 items (felt like standing in lab as opposed to the virtual world, reality of the virtual world).
	(2)	Gender had a significant effect on presence.
	(3)	Order had a significant effect on presence such that the difference between conditions was significant only when the eye mask was used first.

[Regenbrecht 1998] Regenbrecht, H.T., T.W. Schubert, and F. Friedman. 1998. "Measuring the Sense of Presence and Its Relations to Fear of Heights in Virtual Environments." *Inter. Journal of Human-Computer Interaction*, 10(3), 233–249.

Computing platform:	Super Graphics Workstation.
Visual display:	Monoscopic, color Virtual Reality Corp. VR4 HMD. Subject standing on wooden platform that provided an unrestricted interaction space ~ 4 m in diameter.
Tracking:	Polhemus tracking devices.
Object manipulation:	None.
Virtual world:	Virtual world with a virtual cliff approximately 8 m high achieved by lowering parts of the ground. Depth cues provided using linear perspective enhancing lines at edges, special face coloring, and some architectural elements as a reference frame. No texture mapping, no advanced lighting.

Training:	2 min. spent in virtual world before part of the ground was lowered to form a chasm and cliffs.
Experimental task:	Search for some texts in the virtual world and obey instructions given by these texts. These instructions required a subject to move around the virtual world. All tasks were completed if an exit sign was found. 20-min. time limit.
Participants:	37 students and university employees; 23 males; age range 20 to 46; mean age 27 yr. Little or no prior experience with VEs. Nonphobic.
Presence measures:	Questionnaire.
Person-related meas.:	*Fear of heights and avoidance behavior questionnaire*.
Task-related measures:	20-item State-Trait Anxiety Index.
Findings: (1)	Presence and fear of heights had significant positive effects on experienced fear.
(2)	*Avoidance behavior had a significant negative effect on experienced fear.*

[Riecke 2004a] Riecke, B.E., J. Schulte-Pelkum, M.N. Avraamides, and H.H. Bülthoff. 2004a. "Enhancing the Visually Induced Self-Motion Illusion (Vection) Under Natural Viewing Conditions in Virtual Reality." In M. Alcaniz and B. Ref (Eds.), *7th Annual International Workshop: Presence 2004*. Valencia, Spain: Universidad Politecnica de Valencia. 125–132.

Factors:	Foreground markings (present, absent), rotation velocity (20°/s, 40°/s), rotation direction (left, right).
Visual display:	Curved projection screens, one with subtle scratches and markings at upper left to modify the surface and reflection properties. JVC D-ILA DLA-SX21S projector with 1400 × 1050 resolution, corrected for curvature.
Audio display:	Sennheiser HMEC 300 active noise-canceling headphones.
Tracking:	None.
Navigation:	None.
Object manipulation:	None.
Virtual world:	Tübingen market place, scene rotated around vertical axis with constant acceleration for 3 sec., maximum duration of constant velocity rotation 60 sec.
Training:	Familiarization vection stimulus and practice block of 4 trials.
Experimental task:	Participant instructed to pull a force-feedback joystick in the direction of perceived self-motion as soon as it was sensed. 4 repetitions of 2 different rotation velocities, presented in random order, and 2 turning directions presented in alternating order. 16 trials. Participant seated, yielding 54° × 40.5° FOV.
Participants:	22 participants.
Study design:	Between-subjects for foreground marking, within-subjects for rotation velocity and rotation direction.
Presence measures:	IPQ.
Person-related meas.:	Presence Susceptibility Questionnaire, Kennedy SSQ.
Task-related measures:	Vection onset time, vection intensity, convincingness of vection rating, *50% vection onset time, time between vection onset and maximum vection*.
Findings: (1)	Total IPQ scores and all subscales each had a significant positive correlation with convincingness rating.
(2)	The IPQ Involvement/Attention subscale had a significant negative correlation with vection onset time. Presence scores had no significant correlation with vection intensity.
(3)	*Foreground markings and rotation velocity had a significant effect on vection onset time, vection intensity, 50% vection onset time, time between vection onset and maximum vection, convincingness of vection, with increased vection results for the foreground markings and faster rotation velocity.*

[Riecke 2004b] Riecke, B.E., J. Schulte-Pelkum, M.N. Avraamides, M. von der Heyde, and H.H. Bülthoff. 2004b. *The Effect of Cognition on the Visually-Induced Illusion of Self-Motion (Vection).* Available at http://www.kyb.mpg.de/publications/pdfs/pdf2538.pdf.

Factors:	Visual stimulus (natural scene, mosaic-like scrambling, random slices).
Visual display:	Curved projection screen, with FOV 54° × 40.5°.
Tracking:	None.
Navigation:	None.
Object manipulation:	None.
Virtual world:	Photorealistic representation of Tübingen market place.
Experimental task:	Observe rotating scene and report any experience of vection.
Participants:	12 participants.
Study design:	Within-subjects.
Presence measures:	IPQ.
Task-related measures:	*Vection onset time, vection intensity, vection convincingness rating*.
Findings: (1)	Visual stimulus had a significant effect on presence, with increased presence reported for the natural scene.
(2)	*Visual stimulus had a significant effect on vection onset time, vection intensity, and convincingness ratings, with increased vection indicated for the natural scene*.

[Riley 2001] Riley, J.M. 2001. *The Utility of Measures of Attention and Situation Awareness for Quantifying Telepresence*. Ph.D. Dissertation. Mississippi State University, MS.

Factors:	Task complexity (low mine density, moderate mine density, high mine density).
Computing platform:	Intergraph TDZ2000GXI workstation with high-performance graphics subsystems and a Dell PC.
Visual display:	Two 21-in. graphics monitors with 1280 × 1024 resolution, viewed using CrystalEyes stereographic goggles.
Navigation:	Standard mouse used to navigate a simulated robotic vehicle.
Object manipulation:	Keyboard used to give commands to robotic vehicle.
Virtual world:	Audio cues used to present a ringing bell sound whenever part of the robot was directly over a land mine, and an auditory signal marking collisions with objects.
Training:	First training period provided instruction on how to operate the simulated robotic vehicle for teleoperation tasks using the mouse controller and how to manipulate the robotic arm using keyboard and voice commands. Included instruction, demonstration, and hands-on practice. Second training period provided instruction, demonstration, and hands-on practice using the keyboard for completing secondary monitoring tasks and also practice of both tasks performed simultaneously. Third training session provided explanation of Situation Awareness Global Assessment Technique (SAGAT) queries and survey administration during trials, with practice including multi-task performance involving SAGAT freezes and queries. Total time 2 hr.
Experimental task:	The primary task was to operate a robotic vehicle (via voice commands) to locate, uncover, identify, and neutralize 4 land mines. Secondary tasks were to monitor displays for visual signals indicating a critical event associated with the rover and controls in the teleoperation task (one given in VE and other in RE). 30 to 50 min. Two trials.
Participants:	24 university students; 22 males; age range 19 to 26; mean age 20.25 yr. PC and video game experience.
Study design:	Between-subjects.
Presence measures:	19-item subset of Witmer-Singer PQ.
Person-related meas.:	18-item subset of Witmer-Singer ITQ.

Task-related measures:		Modified Cooper-Harper perceived workload scale, SAGAT queries for average situation awareness, hit-to-signal ratios for attention to each monitoring task, and comparison of ratios across monitoring environments.
Performance measures:		Average time to mine neutralization.
Findings:	(1)	Task complexity had a significant negative effect on presence.
	(2)	Presence had no significant relationship with average situation awareness or the ratio of attention scores across VE to RE.
	(3)	Presence had a significant negative correlation with average time to mine neutralization, perceived workload, and hit-to-signal ratio in VE.
	(4)	Presence had a significant positive correlation with ITQ.
	(5)	*Task complexity had a significant negative effect on performance.*
	(6)	*Task performance had a significant negative correlation with perceived workload, average situation awareness, and hit-to-signal ratio in VE.*
	(7)	*Average situation awareness had a significant positive correlation with perceived workload, the ratio of attention across the VE and RE, and hit-to-signal ratio in VE.*
	(8)	*Task complexity had no significant effect on situation awareness, attention, or workload.*

[Riley 1999] Riley, J.M. and D.B. Kaber. 1999. "The Effects of Visual Display Type and Navigational Aid on Performance, Presence, and Workload in Virtual Reality Training of Telerover Navigation." In *Proc. Human Factors and Ergonomics Society 43rd Annual Meeting*. 1251–1255.

Factors:		Visual display (HMD, projection screen, monitor), navigational aid (written directions, plan-view layout).
Visual display:		HMD with 640 × 480 resolution, large projection screen with 600 × 800 resolution, computer monitor with 1280 × 1024 resolution.
Navigation:		Using standard mouse.
Object manipulation:		None.
Experimental task:		Navigate a simulated telerobotic vehicle through an office environment consisting of 9 rooms, and 3 independent paths. 2 trials.
Participants:		24 participants; age range 20 to 42.
Study design:		Between-subjects for display type; within-subjects for navigational aid.
Presence measures:		Witmer-Singer PQ.
Person-related meas.		Witmer-Singer ITQ, Manikin Test, Carter and Wolstad spatial ability test.
Task-related measures:		National Aeronautics and Space Administration (NASA) Task Load Index (TLX).
Performance measures:		Task completion time, route selection.
Findings:	(1)	Visual display had a significant effect on presence, with higher presence ratings given for monitor.
	(2)	Presence significantly increased over the two trials.
	(3)	ITQ had a significant positive correlation with presence.
	(4)	Task performance had a significant negative correlation with presence for map users.
	(5)	Workload had a significant negative correlation with presence.
	(6)	Spatial ability had a significant correlation with presence but not with task performance or workload.
	(7)	*Visual display had no significant effect on performance or workload.*
	(8)	*Navigation aid had a significant effect on navigation time and selection of most efficient route, with increased performance found for map usage.*
	(9)	*Navigation aid had a significant effect on perceived workload, with a lower level of workload reported for map usage.*
	(10)	*Trial order had a significant effect on presence, with participants reporting more presence during the second trial.*

[Robillard 2003] Robillard, G., S. Bouchard, T. Fournier, and P. Renaud. 2003. "Anxiety and Presence During VR Immersion: A Comparative Study of the Reactions of Phobic and Non-Phobic Participants in Therapeutic Virtual Environments Derived From Computer Games." *CyberPsychology & Behavior,* 6(5), 467–476.

Factor:		Participant phobia (present, absent).
Computing platform:		Pentium III PC with ATI Technologies Inc. Radion graphics card.
Visual display:		i-O Display Systems I-Glass HMD, with 480 × 640 resolution, draped with black cloth to eliminate ambient light.
Audio display:		PC stereo speakers.
Tracking:		Intertrax head tracker.
Navigation:		Sidewinder game pad.
Virtual world:		Modified computer game environments: arachnophobia world based on Half-Life, acrophobia and claustrophobia worlds based on Unreal Tournament.
Training:		Exposure to neutral, nonphobic virtual world to gain familiarity with controls.
Experimental task:		Phobic participants had 3 sessions of exposure to appropriate phobic virtual world, where participant was encouraged to approach phobic stimuli as closely as possible. 20-min. exposure for each session. Nonphobic participants had two 5-min. sessions in same virtual world as that of matched phobic participant. Data reported here from first session only.
Participants:		13 participants with diagnosed phobias; 4 males; age range 18–60; mean age 33.7 yr. 13 nonphobic participants; age and gender matched with phobic participants. Prospective participants screened using the Structured Clinical Interview for the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition **(**DSM-IV) disorders, Geer's Fear Survey Schedule II, Spielberger's State-Trait Anxiety Inventory (Form Y), Beck Depression Inventory.
Study design:		Between-subjects.
Presence measures:		French version of Witmer-Singer PQ, with unscored items omitted and using restructured subscales: Realism, Affordance to act, Interface quality, Affordance to examine, Self-Evaluation of performance. Verbal rating of presence queried every 5 min. during exposure.
Person-related meas.:		French version of Witmer-Singer ITQ, with unscored items omitted and restructured subscales: Focus, Involvement, Emotion, Play.
Task-related measures:		Kennedy SSQ. Verbal rating of anxiety and simulator sickness queried every 5 min. during exposure. Verbal rating of perceived realism.
Findings:	(1)	Participant phobia had a significant effect on presence assessed using the PQ Total and PQ Realism, and verbal rating of presence, with phobic participants reporting higher levels of presence and realism.
	(2)	ITQ Total and Emotions subscale had a significant positive correlation with verbal ratings of presence.
	(3)	PQ Total and the Realism and Affordance to examine subscales had a significant positive correlation with verbal ratings of presence.
	(4)	Verbal rating of perceived realism and mean verbal anxiety had a significant positive correlation with verbal ratings of presence.
	(5)	*Participant phobia had no significant effect on SSQ Total and subscale scores.*
	(6)	*Participant phobia had no significant effect on verbal rating of perceived realism.*

[Romano 1998] Romano, D.M., P. Brna, and J.A. Self. 1998. "Collaborative Decision Making and Presence in Shared Dynamic Virtual Environments." In *Proc. 1st International Workshop on Presence in Shared Virtual Environments at BT Labs*, Ipswich, UK.

Factors:	Collaboration (playing game as a team of two, individually).
Computing platform:	2 multimedia PCs.

Visual display: Two 15-in. desktop monitors.
Navigation: Combination of standard 2 DOF mouse and arrow keys.
Object manipulation: Combination of standard 2 DOF mouse and arrow keys.
Virtual world: Multiparticipant virtual game, where virtual world has constraints similar to reality (e.g., participant has to breathe while swimming and dies if shot by hostile creatures). Limited number of lives. Self-representation as gun.
Training: Preliminary training on basic game features for those with no prior experience.
Experimental task: Find way out of maze while surviving the attack of other humans and animals.
Participants: 6 pairs of participants; 5 males; age range mid-20s to mid-30s. Participants knew their partners prior to the study.
Study design: Within-subjects.
Presence measures: 3-item presence questionnaire, 6-item Co-presence Questionnaire.
Person-related meas.: Game playing experience.
Task-related measures: Self-rating of collaboration and performance.
Findings: (1) Collaboration had a positive effect on co-presence.
(2) Self-rating of performance had a positive correlation with presence.
(3) Game experience had a positive relationship with presence.

[Sallnäs 2004 (3)] Sallnäs, E.-L. 2004. *The Effect of Modality on Social Presence, Presence, and Performance in Collaborative Virtual Environments*. Ph.D. Thesis. Kungliga Tekniska Högskolan (Royal Institute of Technology) Stochholm, Sweden.

Factors: Modality (video conference, voice, text-chat).
Computing platform: 2 PowerBook PCs networked via Ethernet. System developed in Active Worlds. In text-chat condition, communication provided using Active Worlds.
Visual display: Two 21-in. desktop monitors.
Audio display: Telephones with headsets.
Virtual world: Picture exhibition with information points that included posters and QuickTime movie clips with audio. Self-representation by human-like avatars.
Experimental task: Decision-making task.
Participants: 80 participants (split between this and other follow-up experiment), working in pairs.
Study design: Between-groups.
Presence measures: Presence questionnaire, Social Presence Questionnaire.
Task-related measures: 14-item perceived Task Performance Questionnaire, frequency of words spoken, frequency of words spoken/sec.
Performance measure: *Time to complete task.*
Findings: (1) Modality had a significant effect on presence, with participants who communicated using text-chat reporting significantly less presence.
(2) Modality had a significant effect on social presence, with participants who communicated using text-chat reporting significantly less social presence.
(3) Modality had a significant effect on task completion time, with those in the text-chat condition taking significantly longer, and dialogues were significantly scarcer and significantly lower words/sec.

[Sallnäs 2004 (4)] Sallnäs, E.-L. 2004. *The Effect of Modality on Social Presence, Presence, and Performance in Collaborative Virtual Environments*. Ph.D. Thesis. Kungliga Tekniska Högskolan (Royal Institute of Technology) Stochholm, Sweden.

Factors: Modality (VE video conference, VE voice, Web video, Web audio).
Computing platform …
Performance measures: As in [Sallnäs 2004 (3)], with the addition of a comparable Web environment condition.

Findings: (1) Virtual or Web modality had no significant effect on presence or social presence. A significant interaction with video/audio was found: participants in the Web video condition reported more presence than those in the Web audio condition.

(2) Modality had a significant effect on social presence, with participants who communicated using text-chat reporting significantly less social presence.

(3) Virtual or Web modality had no significant effect on task completion time but did have a significant effect on word rate with those in the virtual video condition using a substantially lower number of words/sec.

(4) Modality had a significant effect on task completion time, with those in the 2 video conditions taking significantly longer than those in the audio conditions.

[Sallnäs 2004 (6)] Sallnäs, E.-L. 2004. *The Effect of Modality on Social Presence, Presence, and Performance in Collaborative Virtual Environments*. Ph.D. Thesis. Kungliga Tekniska Högskolan (Royal Institute of Technology) Stochholm, Sweden.

Factors:	Haptic force feedback (delivered to fingertip, none).
Computing platform:	Software implemented using Reachin Technologies Corp. Application Programming Interface (API) on a Windows 2000 PC.
Visual display:	Two desktop monitors.
Audio display:	None.
Haptic display:	Two SensAble Technologies Inc. PHANTOMs.
Navigation:	Using haptic display.
Object manipulation:	Using haptic display. When no haptic feedback is provided, PHANTOM operates as a 3-D mouse.
Virtual world:	Room with 2 large shelves with 6 cubes resting on them, and 2 small target shelves.
Experimental task:	Working alternatively, lift a cube and pass it to partner who tapped other shelf with the cube. Partner then returns cube to originator who taps shelf with the cube. Task difficulty adjusted by randomly varying cube size.
Participants:	18 participants, working in pairs.
Presence measures:	Witmer-Singer PQ, 34-item Social Presence Questionnaire.
Task-related measures:	14-item perceived Task Performance Questionnaire.

Findings: (1) Force feedback had a significant effect on presence, with participants receiving force feedback reporting more presence.

(2) Force feedback had a significant effect on social presence, with participants receiving force feedback reporting more social presence.

(3) Perceived performance had a significant correlation with presence but had no correlation with social presence.

(4) Force feedback had a significant effect on perceived performance, with participants receiving force feedback reporting improved performance.

[Sallnäs 2000] Sallnäs, E.-L., R. Rassmus-Gröhn, and C. Sjoström. 2000. "Supporting Presence in Collaborative Environments by Haptic Force Feedback." *ACM Trans. on Computer-Human Interaction*, 7(4), 461–476.

Factors:	Haptic force feedback (delivered to fingertip, none).
Computing platform:	Intergraph workstation. Software developed using GHOST Software Development Kit.
Visual display:	Two 21-in. desktop monitors.
Audio display:	GN Netcom audio headsets using a telephone connection.
Haptic display:	Two SensAble Technologies Inc. PHANTOMs, an "A" and "T" model.
Navigation:	Using haptic display.

Object manipulation: Using haptic display, one participant pushes cubes along the floor or lifts a cube by pressing it against a wall and pushing it up, or participants work together in lifting a cube. If no haptic feedback is provided, PHANTOM operates as a 3-D mouse.
Virtual world: Room containing 8 cubes with simulated form, mass, damping, and surface friction. A slight vibration distinguished between touching a cube and touching or holding on to partner. Force feedback also provided for walls and partner. Self-representation as colored sphere 12 mm in diameter.
Training: Approx. 2 min. learning the interface.
Experimental task: 5 collaborative tasks. Four tasks require building patterns with cubes. Other task requires navigating through a constructed pattern.
Participants: 14 pairs of university students; 14 males; age range 20 to 31; mean age 23 yr. No prior experience with collaborative desktop virtual interfaces.
Study design: Between-groups.
Presence measures: 32-item Witmer-Singer PQ Version 2.0, 8-item Social Presence Questionnaire.
Task-related measures: *14-item Perceived Presence Questionnaire*.
Performance measures: *Time to complete task.*
Findings:
(1) Haptic force feedback had a significant effect on presence, with more presence reported when force feedback was provided.
(2) Haptic force feedback had no significant effect on social presence.
(3) Haptic force feedback had a significant effect on perceived task performance.
(4) Haptic force feedback significantly reduced task completion time.

[Sanders 2002] Sanders, R.D. and M.A. Scorgie. 2002. *The Effect of Sound Delivery Methods on a User's Sense of Presence in a Virtual Environment.* M.Sc. Thesis. Naval Postgraduate School, Monterey, CA.

Factors: Audio delivery (5 speakers and subwoofer, headphones and subwoofer, headphones, no sound).
Computing platform: Alienware computer with Creative Labs Audigy sound card, NVIDIA GeForce3 graphics card. Physiological data capture and analysis using Thought Technology's BioGraph software and ProComp.
Audio display: Seeheiser Model HD570 headphones, 5 Genelec 1031A active speakers and 1 Genelec 1094A active 400 watt subwoofer system.
Virtual world: Medal of Honor: Allied Assault computer game, Omaha Beach Landing of the Normany Invasion scenario. 10 min. allowed.
Training: Playing game, follow directions of "drill instructor" and complete the Basic Training scenario.
Experimental task: Starting from a position on the beach shingle, clear out the bunkers defending the beach.
Participants: 80 participants; 76 males.
Study design: Between-subjects.
Presence measures: 6-item SUS Questionnaire, Witmer-Singer PQ, Δheart rate, Δskin conductance, Δskin temperature.
Person-related meas.: Age, gender, game experience, caffeine, sleep.
Task-related measures: Witmer-Singer ITQ.
Findings:
(1) Audio delivery had a significant effect on PQ and SUS Questionnaire scores, with all sound conditions resulting in more presence than no sound. Type of delivery had no effect.
(2) Audio delivery had a significant effect on temperature, with a large decrease in temperature for any sound condition, compared with no sound, and for speakers and any headphone condition. There was no significant effect on either heart rate or electrodermal activity.
(3) PQ scores had a significant positive correlation with SUS Questionnaire scores.
(4) PQ scores had a significant positive correlation with ITQ scores.
(5) PQ scores had a significant positive correlation with electrodermal activity and heart rate but not with temperature.

(6) SUS Questionnaire scores had a significant positive correlation with electrodermal activity but not with changes in heart rate or temperature.

(7) Game experience had a significant positive correlation with PQ scores. Caffeine had a significant positive correlation with PQ scores ($p < 0.10$). Age, gender, and sleep had no significant relationship.

[Sas 2003a] Sas, C. and G. O'Hare. 2003a. "Impact of Cognitive Style Upon Sense of Presence." In *Proc. 10th International Conference on Human Computer Interaction*, 22–22 August, Crete, Greece.

Factors:	Cognitive style.
VE System:	Non-immersive ECHOES system.
Virtual world:	Multi-story building where levels containing several furnished rooms are connected by virtual elevators. Each room supports a cohesive set of functions.
Training:	Gain familiarity with the environment and learn movement controls.
Experimental task:	Exploration task followed by search task where participants asked to find a valuable painting hidden in the building. Approx. 25 min.
Participants:	30 undergraduate and postgraduate students; 18 males; age range 20–38.
Presence measures:	Questionnaire.
Person-related meas.:	Myers-Briggs Type indicator.
Task-related measures:	Number of navigation collisions.
Performance measures:	Time to complete search.
Findings: (1)	Cognitive style had a significant effect on presence, with participants classified as more Feeling or more Sensitive experiencing a higher level of presence.
(2)	Time to complete the task had a significant positive correlation with presence.
(3)	Number of collisions had a significant positive correlation with presence.

[Sas 2003b] Sas, C. and G. O'Hare. 2003b. "The Presence Equation: An Investigation Into Cognitive Factors Underlying Presence." *Presence: Teleoperators & Virtual Environments,* 12(5), 523–527.

Factors:	Cognitive style (absorption, creative imagination, empathy, cognitive type), gender.
Virtual world:	ECHOES training environment for maintenance of complex industrial artifacts. Provides a virtual 4-story building, with numerous rooms on each floor, including a conference room, lobby room, training room, and elevator. Specific user activities are associated with each room.
Training:	Exploratory task to gain familiarity with the environment and navigation control. 25-min. time limit.
Experimental task:	Search tasks include finding a hidden painting and finding the library and specific information within the library given spatial landmarks.
Participants:	15 undergraduate and postgraduate students; 9 males; age range 20 to 38.
Study design:	Within-subjects.
Presence measures:	Questionnaire, SUS Questionnaire.
Person-related meas.:	TAS, Creative Imagination Scale, Davis' Interpersonal Reactivity Index, Myers Briggs Type Indicator, gender.
Findings: (1)	Creative imagination score and interpersonal reactivity index had a significant positive correlation with presence. Absorption and cognitive type had no significant correlation with presence.
(2)	Gender had no significant effect on presence, absorption, or creative imagination but had a significant effect on empathy, with increased empathy reported for females.
(3)	Presence score had a significant positive correlation with SUS questionnaire score.

[Schroeder 2001] Schroeder, R., A. Steed, A.-S. Axelsson, I. Heldal, Å. Abelin, J. Wideström, A. Nilsson, and M. Slater. 2001. “Collaborating in Networked Immersive Spaces: As Good As Being Together?” *Computers & Graphics*, 25, 781–788.

Factors:	Environment type (1 participant in each of two 5-sided Caves, 1 participant in 5-sided Cave, and 1 participant using desktop, real world).
Computing platform:	SGI Onyx2 Infinite Reality with fourteen 250-MHz R10000 MIPS processors, 2 GB RAM, 3 Infinite Reality graphics pipes. SGI Onyx2 with eight 300-MHz R12000 MIPS processors, 8 GB RAM, 4 Infinite Reality graphics pipes. SGI O2 with 1 MIPS R1000 processor, 256 MB RAM. DIVE toolkit, DIVEBONE connection, and dVise 6.0 software with SGI Performer renderer. Network lag ~ 180 ms between Onyx 2 systems; less between the first and third systems.
Visual display:	3 × 3 × 3 m TAN VR-CUBE with projection on 5 walls (no ceiling), stereoscopic viewing using Stereographics Corp. CrystalEyes shutter glasses; rendering performance at least 30 Hz. Trimension ReaCTor with projections on 3 × 2.2 m walls and 3 × 3 m floor, stereoscopic viewing CrystalEyes shutter glasses; rendering performance 45 Hz. 19-in. monitor; rendering performance at least 20 Hz.
Audio display:	Robust Audio Toolkit for communication between participants, except on one occasion when 2 mobile phones were used.
Tracking:	Polhemus tracking of both shutter glasses and hand for VR-CUBE, Intersense IS900 system tracking for shutter glasses and interaction device for ReaCTor.
Navigation:	Using 3-D wand with VR-CUBE system, interaction device with 4 buttons and analogue joystick with ReaCTor system (locomotion enabled), by moving middle button on a standard 3-button mouse with desktop system.
Object manipulation:	Select objects by putting virtual hand into a virtual cube and press/release wand/joystick button to move object or by using standard mouse buttons.
Virtual world:	Participant represented to partner as a simple human-like male avatar with jointed arm; self-representation as virtual hand.
Experimental task:	Two participants cooperate to solve a puzzle by arranging eight 30 sq. cm. colored blocks into a cube such that each side of the completed cube displays a single color. 20 min. time limit.
Participants:	66 pairs of participants.
Study design:	Between-groups.
Presence measures:	2-item presence questionnaire, 1-item place-to-visit rating.
Task-related measures:	*3 items on collaboration, 3 items on contribution to Task Questionnaire*.
Performance measures:	*Time to complete task.*

Findings:

(1) Visual display had a significant effort on presence, with higher presence reported by immersed participants compared with desktop participants. There was no difference between immersive systems.

(2) Visual display had a significant effect on place-to-visit rating, with higher presence reported by immersed participants compared with desktop participants. There was no difference between immersive systems. Immersed participants whose partner was also immersed reported significantly more presence than those whose partner used the desktop system.

(3) Visual display had a significant effect on co-presence, with immersed participants using the 5-sided Cave reporting higher presence than desktop users. Also, participants who were both immersed reported significant higher presence than the immersed participant (5-sided Cave) with desktop partner.

(4) Environment type (real and 2 participants using projection displays) had no significant effect on time to complete task.

(5) Visual display had no significant effect on rating of collaboration.

(6) Visual display had a significant effect on rating of contribution, such that immersive participants were rated as more active than desktop participants, but had no significant difference in amount of verbal communication.

[Schubert 2000 (1)] Schubert, T., H. Regenbrecht, and F. Friedmann. 2000. *Real and Illusory Interaction Enhance Presence in Virtual Environments*. Submitted to Presence 2000, 3rd International Workshop on Presence. 27–28 March, Delft University of Technology, Delft, The Netherlands.

Factors:		Type of movement (self-movement, preset), agents (present, absent).
Computing platform:		SGI workstation.
Visual display:		Virtual Research VR4 HMD. Update rate ~ 15 Hz. In preset movement condition, a pre-recorded presentation showing the VE from the viewpoint of a person slowly wandering and looking around was presented on the HMD. Participant standing.
Tracking:		Polhemus Fastrak for head-tracking in self-movement condition.
Navigation:		When viewpoint was under participant control, participant could change viewpoint by turning his head and/or walking around in a circle 5 m in diameter. In other condition, participant had no control of navigation.
Object manipulation:		None.
Virtual world:		Hallway representing an administration building. Participant stands at an intersection, looking into 4 corridors with numerous doors. Across the wall, several plates are visible. Circle boundary marked with red line. In the agents-present condition, doors opened and closed from time to time and 2 comic-strip-like shoes came out of the doors, walked across the hall, and entered other rooms.
Training:		Brief verbal description of the VE technology, especially the HMD, and the virtual world participants would experience.
Experimental task:		Count number of plates on the wall. 5 min. time limit.
Participants:		56 students and university staff members; 34 males; age range 19 to 61; mean age 29.3 yr.
Study design:		Between-subjects.
Presence measures:		IPQ.
Findings:	(1)	Type of movement had a significant effect on spatial presence and realness, with increased presence reported for self-movement, but had no significant effect on involvement.
	(2)	Agents had no significant effect on any category of presence.

[Schubert 2000 (2)] Schubert, T., H. Regenbrecht, and F. Friedmann. 2000. *Real and Illusory Interaction Enhance Presence in Virtual Environments*. Submitted to Presence 2000, 3rd International Workshop on Presence. 27–28 March, Delft University of Technology, Delft, The Netherlands.

Factors:		Agent interaction (expected, not expected).
Computer platform:		SGI workstation.
Visual display:		Virtual Research VR4 HMD. Update rate ~ 15 Hz. Participant standing.
Tracking:		Polhemus Fastrak for head-tracking in self-movement condition.
Navigation:		Free movement in a circle 5 m in diameter.
Object manipulation:		None.
Virtual world:		As in [Schubert 2000 (1)].
Training:		Brief verbal description of the VE technology, especially the HMD, and the virtual world participants would experience. Participants were also told they would see other characters in the virtual world. Half the participants were told these characters would react to the participant's actions. The others were told no interactions were possible.
Experimental task:		Count number of plates on the wall. 5 min. time limit.
Participants:		26 students; 4 males; age range 15 to 41; mean age 24.6 yr.
Study design:		Between-subjects.
Presence measures:		IPQ.
Finding:	(1)	Expectation of agent interaction had a significant positive effect on spatial presence only.

[Schuemie 2005] Schuemie, M.J., B. Abel, C.A.P.G. van der Mast, M. Krijn, and P.M.G. Emmelkamp. 2005. "The Effect of Locomotion Technique on Presence, Fear, and Usability in a Virtual Environment." In M. Al-Akaidi and L. Rothkrantz (Eds.), *Proc. Euromedia 2005*. 11–13 April, Toulouse, France.

Factors:	Navigation (walking-in-place, hand-controlled, gaze-directed).
Computing platform:	PC with 3D Labs Oxygen G420 graphics card. Frame rate fixed at 15 fps.
Visual display:	Visette Pro HMD with FOV 70º diagonal, resolution 640 × 480.
Tracking:	Head-tracking using Ascension Technology Flock of Birds.
Navigation:	Using walking-in-place, trackball, or head-tracking.
Virtual world:	Room designed to determine controllability of interaction techniques with objects such as couches and plants. One spot marked with a flag, which, when participant pressed button, would disappear and reappear somewhere else. A separate area, representing the outside of a tall building, reached by an elevator, containing height situations designed to determine effect of locomotion on fear.
Training:	In separate training room for gaining familiarity with interface.
Experimental task:	Navigate around objects to the flag trying to avoid collisions, pressing button when reaching flag, repeat as flag moved to another six positions. Then take elevator and, in new space, locate boxes. At each box, look inside to determine what figure was inside.
Participants:	42 participants; 19 males; age range 18 to 60; mean age 30.4 yr. 3 subjects unable to complete because of extreme fear.
Presence measures:	IPQ.
Person-related meas.:	Age, gender, Acrophobia Questionnaire (AQ), *Motion Sickness Tendency (MST) Questionnaire,* Computer Experience (CE) Questionnaire, TAS.
Task-related measures:	*Subjective Units of Discomfort (SUD) rating of fear, heart rate, head-down rotations, avoidance of edge of large drop, Kennedy SSQ, Usability Questionnaire.*
Performance measures:	*Number of collisions, accuracy in positioning near flags*.

Findings:

(1) Locomotion technique had a significant effect on presence, with most presence reported for walking-in-place.

(2) Each AQ score, gender, computer experience, and TAS scores have no significant correlation with IPQ scores.

(3) Age had a significant positive correlation with IPQ scores.

(4) Locomotion technique had a significant effect on SUD scores, with most fear reported for walking-in-place.

(5) Locomotion technique had no significant effect on avoidance measure.

(6) Locomotion technique had a significant effect on SSQ scores, with most symptoms reported for gaze directed and walking-in-place where head-tracking used.

(7) Locomotion technique had no significant effect on usability scores.

(8) Locomotion technique had no significant effect on positioning accuracy but had a significant effect on number of collisions, with walking-in-place participants showing more collisions.

[Seay 2001] Seay, A.F., D.M. Krum, L. Hodges, and W. Kibarsky. 2001. "Simulator Sickness and Presence in a High FOV Virtual Environment." In *Proc. Conference on Human Factors in Computing Systems*. 31 March–5 April, Seattle, WA.

Factors:	FOV (180º, 60º), stereopsis (present, absent), interactivity (driver, passenger).
Computing platform:	Non-expensive Automatic Virtual Environment (NAVE).
Visual display:	Three 8 × 6 ft. screens, with sides positioned at 120º to center screen. Used in single-screen and three-screen configuration. User seated in front of center screen.
Navigation:	Using joystick.
Experimental task:	10 min.
Participants:	156 undergraduates, grouped into pairs; 133 males; age range 17 to 38 yr.

Study design:		Within-subjects.
Presence measures:		Witmer-Singer PQ.
Person-related meas.:		Witmer-Singer ITQ.
Task-related measures:		*Kennedy SSQ.*
Findings:	(1)	FOV had a significant effect on PQ scores, with more presence reported for the larger FOV.
	(2)	Interactivity had a significant effect on PQ scores, with more presence reported by the driver.
	(3)	ITQ and SSQ scores had no significant correlation with PQ scores or with each other. Except when experiments conditions were controlled for, that was a significant positive correlation between PQ and ITQ scores.
	(4)	*FOV had a significant effect on SSQ scores, with more nausea reported by participants with the larger FOV. There was a significant interaction effect with interactivity.*
	(5)	*FOV and interactivity had a significant interaction effect on SSQ Oculomotor Discomfort and Disorientation subscale scores.*

[Shim 2003] Shim, W. and G.J. Kim. 2003. "Designing for Presence and Performance: The Case of the Virtual Fish Tank." *Presence*, 12(4), 374–386.

Factors:		Level of detail (high, low), FOV (180º, 150º, 120º).
Computing platform:		3 Pentium III PCs with NvidiaQuadro-based graphic accelerator cards running Windows 2000. Software developed using Sense8 Corp. WorldToolKit.
Visual display:		3 desktop monitors; participant with fixed head position with viewing distance 1 m.
Audio display:		None.
Tracking:		None.
Navigation:		None.
Object manipulation:		None.
Virtual world:		Virtual fish tank containing 30 fish that exhibited different levels of behaviors.
Training:		None.
Experimental task:		Watch display for 90 sec. for each (of 6) viewing combination(s).
Participants:		23 undergraduate students; 20 males; age range 19 to 27.
Study design:		Within-subjects.
Presence measures:		8-item version of Witmer-Singer PQ.
Person-related meas.:		4-item version of Witmer-Singer ITQ.
Findings:	(1)	Level of detail had a significant effect on presence, with a high level of detail producing more presence than a low level of detail.
	(2)	FOV had a significant effect on presence, with 180º producing more presence than 120º.

[Singer 1998] Singer, M.J., J.A. Ehrlich, and R.C. Allen. August 1998. *Effect of a Body Model on Performance in a Virtual Environment Search Task.* Technical Report 1087. U.S. Army Research Institute for the Behavioral and Social Sciences.

Factors:	Self-representation (body model, pointer).
Computing platform:	SGI ONYX, with Performer and in-house software.
Visual display:	Virtual Research Corp. VR4 HMD with 742 × 230 color pixels/eye, FOV 48ºH × 36ºV. Participant eye height used to adjust display.
Tracking:	Head, shoulder, feet, right arm, and right hand using Ascension Flock of Birds.
Object manipulation:	In-house manufactured hand-held wand with button used to make target disappear.
Virtual world:	12 different room configurations, rated as medium or low complexity. Typical office spaces and furniture. Three targets (briefcases) placed in each 6-room trial set.

Training:	View videotape demonstrating moving and acquiring targets. Then guided through a locomotion and acquisition practice session in VE practice room.
Experimental task:	Search for briefcases hidden in office rooms. 6 trials.
Participants:	32 participants; 18 males; age range 18 to 44; mean age 22.5 yr. Low scores on initial SSQ and averaged 8 hr./week computer use. Four participants had prior VE experience.
Presence measures:	Witmer-Singer PQ.
Person-related meas.:	Witmer-Singer ITQ.
Performance meas.:	*Number of targets acquired, time to complete search, number of collisions. Also for each target room, time/collisions to visual acquisition of target, time/collisions to physical acquisition, time/collisions to exit.*
Findings: (1)	Self-representation had no significant effect on presence.
(2)	*Self-representation had no significant effect on the number of targets acquired or on any time/collision measures*.

[Singer 1997] Singer, M.J., R.C. Allen, D.P. McDonald, and J.P. Gildea. February 1997. *Terrain Appreciation in Virtual Environments: Spatial Knowledge Acquisition*. Technical Report 1056. U.S. Army Research Institute for the Behavioral and Social Sciences.

Factors:	Level of equipment (Hi-VE with head-tracking, and treadmill movement control; Low-VE with no head-tracking and joystick movement control; standard map training), level of detail (realistic, abstract terrain).
Computing platform:	SGI Onyx. In-house software.
Visual display:	VR4 HMD with 742 × 230 color pixels/eye, FOV 48º × 36º.
Tracking:	Isotracks for head and hand tracking. Polhemus sensor strapped over 1st knuckle of the index finger for pointing.
Navigation:	In the Hi-VE condition, used a treadmill where normal walking speeds were translated into a constant walking pace within the terrain database, movement in the direction of gaze. In the Low-VE condition, movement was controlled by Gravis 6 DOF joystick and pointing.
Object manipulation:	Pointing wand for indicating directions or locations and selecting objects.
Virtual world:	Two terrains: (1) Abstract terrain derived from composite topographical maps; (2) Terrain developed from topographical map and aerial photography of 1-km area east of the McKenna Military Operations in Urban Terrain, Ft. Benning.
Training:	Topographical map training packet. Also, VE movement and control practiced using the VEPAB doorways and fixed tracking tasks, see Singer 1995.
Experimental task:	Participants briefed on the terrain and path to be followed. While navigating terrain, at each of 3 checkpoints, participants locate several previously studied landmarks, identify 2 possible threatening terrain areas, and then cross the terrain following previously indicated route. Feedback on correct orientation and distance provided after each landmark identification, and information provided about the direction and distance to the next checkpoint.
Participants:	48 university students; 30 males; age range 18 to 44; mean age 24.6 yr. Passed test of topographical map knowledge. Relatively naïve about VEs.
Study design:	Between-subjects.
Presence measures:	32-item Witmer-Singer PQ Version 3.0.
Person-related meas.:	34-item Witmer-Singer ITQ Version 3.0, *VE and computer experience*, *spatial abilities.*
Task-related measures:	Kennedy SSQ, time spent in VE.
Performance measures:	Spatial knowledge acquisition assessed by accuracy in pointing to landmarks from new positions in the terrain, and projective convergence to measure accuracy of cognitive map.
Findings: (1)	Level of equipment and level of detail had no significant effect on PQ Total or Involvement/Control subscales.

(2) Time spent in the VE had a significant positive correlation with PQ Total and Involvement/Control subscale.
(3) ITQ Focus subscale had a significant positive correlation with PQ Total and Involved/Control and Naturalness subscales. ITQ Involvement had a significant negative correlation with PQ Interface Quality subscale.
(4) SSQ Motion Sickness, Disorientation, and Oculomotor subscales had a significant negative correlation with PQ Interface Quality subscale.
(5) Mean number of correct landmark directional identification, mean number of correct visually available landmark directional identification, mean correct identifications of individual landmarks, and mean percent of correctly identified visually available individual landmarks each had a significant positive correlation with PQ Involvement/Control subscale.
(6) Average projective convergency measures of accuracy and consistency had a significant positive correlation with PQ Interface Quality subscale.
(7) Fidelity and level of abstraction each had a significant effect on landmark identification pointing accuracy, with participants in the Hi-VE condition achieving more accuracy that those in the map condition.
(8) Fidelity had no significant effect on accuracy and consistency of cognitive map but level of abstraction had a significant effect, with improved performance found for the abstract map representation.
(9) Person-related measures (except for ITQ scores) had no significant correlation with spatial knowledge.
(10) Fidelity and type of terrain had a significant effect on only ITQ Total and Involvement/Control subscale.
(11) SSQ pre-experiment scales had a significant negative correlation with ITQ Focus and Disorientation subscales, and SSQ Oculomotor subscale had a significant positive correlation with ITQ Involvement/Control subscale. SSQ post-experiment scales had no significant correlation with ITQ subscales.
(12) Mean correct identifications of individual landmarks, mean correct directional identifications of visually available landmarks, and mean correct directional identifications on nonvisually available landmarks had a significant positive correlation with ITQ Games subscale. No significant correlation with ITQ Total.

[Singer 1995] Singer, M.J., J. Ehrlich, S. Cinq-Mars, and J.-P. Papin. December 1995. *Task Performance in Virtual Environments: Stereoscopic Versus Monoscopic Displays and Head Coupling*. Technical Report 1034. U.S. Army Research Institute for the Behavioral and Social Sciences.

Factors:	Stereopsis (present, absent), head-tracking (present, absent).
Computing platform:	SGI Reality Engine. Sense8 software.
Visual display:	Flight Helmet HMD with 360 × 240 color pixels/eye, FOV 83°. IPD set for each participant. Participant remained seated.
Tracking:	Polhemus Isotrack for head-tracking.
Navigation:	Movement controlled by 6 DOF joystick.
Object manipulation:	Object selection, tracking, manipulation using 6 DOF joystick.
Virtual world:	VEPAB worlds consisting of a series of simple VEs each focused on one task. No self-representation.
Experimental task:	VEPAB tasks: Doorways—move through 10 rooms with doors at various locations on the opposing walls. Bins—use a 3-D crossed-line cursor to select a target ball in one of 9 bins and move it to a bin marked by an “X.” Fixed-tracking—place cursor on a stationary 0.7-ft. diameter ball-shaped target, where ball appears at locations 5 to 19.5 ft. away; target disappears after 20 sec. Moving target—use cursor to track a ball that moves in a straight line with a randomly generated slope. Target takes 13–19 sec. to traverse the room. Distance estimation—identify an object (soldier) starting at 40 ft. away and judge his height. Then estimate when the object is 30, 20, 10, 5, 2.5 ft. away.

Participants:	48 participants; 36 males; age range 18 to 50; mean age 23.6 yr. No prior VE research experience.
Study design:	Between-subjects.
Presence measures:	32-item Witmer-Singer PQ Version 2.0.
Person-related meas.	9-item Witmer-Singer ITQ, Hidden Figure Test for cognitive style.
Task-related measures:	Kennedy SSQ.
Performance measures:	Doorways—time to cross each room, number of collisions in each room. Bins—time to "grab" ball, total performance time, accuracy. Fixed target—percentage of total time cursor kept on target, time to first intercept. Moving target—percentage of total trial time during which cursor is kept on target, time to first intercept. Distance estimation—accuracy of distance judgments.

Findings:

(1) Stereopsis and head-tracking had a significant interaction effect on presence.
(2) ITQ Total had a significant positive correlation with PQ Total.
(3) SSQ Total and subscales had no significant correlation with PQ Total or subscales.
(4) Cognitive style had no significant correlation with any of PQ Total and subscales, and ITQ Total and subscales.
(5) Performance measures for the tasks had no significant correlation with PQ Total or subscales.
(6) Interaction of stereopsis and head-tracking had a significant effect on ITQ Games subscale.
(7) Pre-test SSQ Oculomotor subscale had a significant positive correlation with ITQ Focus. Post-test SSQ Total and Oculomotor subscale each had a significant negative correlation with ITQ Focus.

[Slater 2004] Slater, M., D.-P. Pertaub, C. Barker, and D. Clark. 2004. "An Experimental Study on Fear of Public Speaking Using a Virtual Environment." Presented at the 3rd International Workshop on Virtual Rehabilitation, 16 September, Lausanne, Switzerland.

Factors:	Anxiety stimulus (empty room, audience).
Computing platform:	SGI Onyx with twin 196-MHz R10000, Infinite Reality graphics, 192 MB of main memory; DIVE software, with Parke and Waters software for generating avatar faces and muscle movement.
Visual display:	Virtual Research Corp. VR8 HMD.
Tracking:	Head-tracking using Polhemus Fastrak.
Navigation:	None.
Object manipulation:	None.
Virtual world:	One virtual world was an empty seminar room with table and chairs; the other virtual world was a room populated with a neutrally behaving audience of 5 people seated around the table. Behaviors consisted of movement of the upper face to indicate degree of interest, eye contact and direction, and gestures with no intrinsic evaluative content and those whose meaning was ambiguous. Avatars' faces and clothing were texture mapped.
Experimental task:	Give a 5-min. talk in a seminar room, without notes or other visual aids. (5 min. previously given to prepare the talk on a subject of participant's choice.)
Participants:	36 respondents to advertisements, with Personal Report of Confidence as a Public Speaker (PRCS) scores in the bottom third or top third and no evidence of psychotism; 20 confident public speakers, 16 phobic.
Study design:	Between-subjects.
Presence measures:	Modified post-talk PRCS, self-assessment of Somatic Response Questionnaire, heart-rate.
Person-related meas.:	PRCS Questionnaire.

Findings:	(1)	For participants in the phobic group, anxiety stimulus also had a significant effect on post-talk PRCS scores, with higher scores given for the audience condition. Anxiety stimulus had no significant effect on nonphobic participants. Phobic participants gave significant higher scores than nonphobic participants.
	(2)	For participants in the phobic group, anxiety stimulus also had a significant effect on self-assessed somatic response scores, with higher scores given for the audience condition.
	(3)	For participants in the phobic group only, anxiety stimulus also had a significant effect on heart rate trends.

[Slater 2000a] Slater, M and A. Steed. 2000. "A Virtual Presence Counter." *Presence*, 9(5), 413–434.

Factors:		Movement (reaching out to touch chess piece, mouse click).
Computing platform:		SGI Onyx with twin 196-MHz R10000, Infinite Reality graphics and 64 MB of main memory. Division, Ltd. dVS and dVISE 3.1.2 software.
Visual display:		Stereoscopic Virtual Research VR4 HMD with 742 × 230 pixels/eye, 170,660 color elements, FOV 67° diagonal with 85° overlap. Frame rate ≥ 20 Hz. Latency approximately 120 ms.
Tracking:		Two Polhemus Fastraks for head and mouse tracking.
Navigation:		Moved in direction of gaze by pressing thumb button on mouse. Constant velocity.
Object manipulation:		Hand-held 5-button 3 DOF mouse. Interaction with chess piece by either pressing a button on the 3-D mouse or by reaching out and "touching" the object.
Virtual world:		Field connected to a virtual anteroom by a door. Field with trees and plants and a 3-D chessboard placed on a table positioned 5 m from the door. Self-representation as simple inverse kinematic virtual body, with visible arm and hand. Total polygon count 13,298.
Training:		Provided in a virtual anteroom where shown how to move around, how to make a small red cube on a table respond by either touching it or clicking mouse button.
Experimental task:		Navigate through a door to outside scene and find 3-D chessboard, find and select a specified chess piece, and observe a sequence of moves. Then, press red button and, when sky turns dark, return from field to starting room.
Participants:		20 university students and staff; 18 males.
Study design:		Between-subjects.
Presence measures:		5-item SUS Questionnaire, BIPs.
Findings:	(1)	Movement (taking hand movement into account) had a significant positive effect on BIP measure for the active group only.
	(2)	BIP measure had a significant positive correlation with subjective presence.

[Slater 2000b] Slater, M., A. Sadagic, M. Usoh, and R. Schroeder. 2000. "Small-Group Behavior in a Virtual and Real Environment: A Comparative Study." *Presence*, 9(1), 37–51. Also discussed in Steed (1999), Tromp 1998 (2).

Factors:	Visual display (HMD, desktop).
Computing platform:	SGI Onyx with twin 196-MHz R10000, Infinite Reality graphics, and 64 MB of main memory, running Irix 6.2. SGI High Impact system with 200-MHz R4400 and 64 MB of main memory. SGI O2 running at 180 MHz on Irix 6.3 with an R5000 processor and 32 MB of main memory. DIVE 3.2 and RAT v.3.023 system.
Visual display:	Stereoscopic Virtual Reality VR4 HMD with 742 × 230 pixels/eye, 170,660 color elements, FOV 67° diagonal with 85° overlap. Frame rate ≥ 20 Hz. Latency approximately 120 ms. 21-in. monitor, 17-in. monitor.
Audio display:	Earphones.
Tracking:	Two Polhemus Fastraks for tracking head and 3-D mouse.

Navigation:	Immersive participant moved in direction of gaze at constant velocity by pressing button on 3-D mouse. Desktop participants moved by using the keyboard arrow keys.
Object manipulation:	None.
Virtual world:	Model of actual laboratory where study took place. Includes a virtual room that had sheets of papers displayed around the walls. Each sheet had several words in a column, each preceded by a number. The words across all sheets with a common number combined to form a saying. Each participant represented by a basic DIVE avatar, differing only in color (Red, Green, Blue), only visible to immersed (Red) participant. Approximately 3,500 polygons.
Training:	Learning to move through the environment.
Experimental task:	Group of 3 strangers meet in the VE and locate the room with puzzle. Figure out what puzzle is and then unscramble as many sayings as possible. One desktop participant (Green) was also tasked to monitor Red as closely as possible, always trying to be in Red's line of vision, moving temporarily when requested by Red. Leave the VE after about 15 minutes. Don jacket the same color as avatar and, after answering a 10-min. questionnaire, meet other participants outside the matching real room. Enter real room and continue task for about 15 min.
Participants:	10 groups of 3 participants recruited from a university campus.
Study design:	Between-subjects.
Presence measures:	2-item SUS Questionnaire, Co-presence Questionnaire.
Person-related meas.:	*Gender*.
Task-related measures:	Individual Accord Questionnaire, including 1 item on enjoyment and an overall rating of accord.
Performance measures:	*Number of riddles solved*.
Findings: (1)	Visual display had no significant effect on presence**.**
(2)	Co-presence had a significant positive correlation with presence.
(3)	Individual accord had a significant positive correlation with combined and presence, co-presence.
(4)	*Number of riddles solved had a significant positive effect on individual accord.*
(5)	*Gender had a significant effect on individual accord, with females reporting increased accord.*

[Slater 1999] Slater, M., D.-P. Pertaub, and A. Steed. 1999. "Public Speaking in Virtual Reality." *IEEE Computer Graphics and Applications*, 19(2), 6–9.

Factors:	Visual display (HMD, monitor), audience response type (positive, negative).
Computing platform:	SGI Onyx with twin 196-MHz R10000, Infinite Reality graphics, and 192 MB of main memory. DIVE V3.3 software.
Visual display:	Stereoscopic Virtual Reality VR4 HMD with 742 × 230 pixel resolution/eye, FOV 67° at 85°overlap, 170,660 color elements. Frame rate ≥ 10 Hz in stereo. Display lag ~ 100 ms.
Tracking:	Two Polhemus Fastraks for HMD and mouse.
Navigation:	Move in gaze direction at constant velocity when thumb pressed a button on hand-held 5-button 3 DOF mouse.
Object manipulation:	None.
Virtual world:	Virtual seminar room populated with audience of 8 avatars seated in semicircle. Avatars continuously displayed scripted behaviors (with human-operator-directed timing) such as paying attention, clapping, talking to other audience members, head and body movements, and random behaviors such as twitching and blinking.
Experimental task:	Practice a 5-min. talk with a positive and a negative audience. Then give talk to an audience that started hostile and ended up positive.
Participants:	10 students and faculty members; 9 males; age range 20 to 40.
Presence measures:	4-item Co-presence Questionnaire.
Task-related measures:	Perceived audience interest rating, self-rating of performance.

Findings:	(1)	Visual display had no significant effect on co-presence.
	(2)	For monitor participants, self-rating of performance had a negative correlation with co-presence. For HMD participants, rating had a negative correlation for the negative audience and positive correlation for the positive audience.
	(3)	*Perceived audience interest had a positive correlation with self-rating of performance for a negative audience only*.

[Slater 1998] Slater, M., A. Steed, J. McCarthy, and F. Maringelli. 1998. "The Influence of Body Movement on Subjective Presence in Virtual Environments." *Human Factors*, 40(3), 469–477.

Factors:		Movement (trees with large variation in height, low variation), task complexity (count number diseased plants, count and remember location of diseased plants).
Computing platform:		SGI Onyx with twin 196-MHz R10000, Infinite Reality graphics, and 64 MB of main memory. Division, Ltd. dVS and dVISE 3.1.2 software.
Visual display:		Stereoscopic Virtual Reality VR4 HMD with 742 × 230 pixel resolution/eye, FOV 67° at 85°overlap, 170,660 color elements. Frame rate ≥ 10 Hz in stereo. Display lag approximately 100 ms.
Tracking:		Polhemus Fastrak for HMD and mouse.
Navigation:		Move in gaze direction at constant velocity when thumb pressed a button on hand-held 5-button 3 DOF mouse.
Object manipulation:		None.
Virtual world:		Training lab connected via a door to a 90 × 75 m field containing 150 plants or trees with large leaves, distributed randomly through the field. Each tree 2.4 m across with 16 leaves. Healthy trees had green leaves, diseased trees had leaves (1 or 4) with brown underside. Trees were classed as healthy, trees with 1 bad leaf, or trees with 4 bad leaves, in equal proportion. Distribution of heights 1.7 ± 0.1 m for low-variation field and 2.35 ± 1.9 m for high-variation field. Self-representation as simple inverse kinematic virtual body. Total scene 32,576 triangles.
Training:		Training tasks in a virtual lab matching real lab where experiment performed.
Experimental task:		Simple task: move through field to count the number of diseased plants. Complex task: count number of diseased plants and remember where they were to draw on a map later. After about 3 min., sky brightened as a signal to start moving back to training lab.
Participants:		20 university students and staff, and journalists; 13 males.
Study design:		Between-subjects.
Presence measures:		6-item SUS Questionnaire.
Person-related meas.:		Gender.
Task characteristics:		Task complexity.
Findings:	(1)	Movement had a significant effect on reported presence, positive for head yaw, negative for extent of bending.
	(2)	Task complexity and gender had no significant effect on presence individually, but there was a significant interaction between task complexity and gender, with females in the more complex task reporting lower presence than in the simpler task.

[Slater 1996] Slater, M., M. Usoh, V. Linakis, and R. Kooper. 1996. "Immersion, Presence, and Performance in Virtual Environments: An Experiment With Tri-Dimensional Chess." In *Proc. ACM Symposium on Virtual Reality and Technology (VRST '96)*, 1–4 July, Hong Kong. 163–172.

Factors:	Visual display (HMD, desktop), scene realism (realistic setting with chessboard in a garden setting, plain setting with chessboard suspended in void).
Computing platform:	Division, Ltd. ProVision 100 system. Board and chess pieces modeled in AutoCAD.

Visual display:	Stereoscopic, color Virtual Reality VR4 HMD with 360 × 240 pixels per eye (overall 704 × 480), FOV ~ 75° H × 40° V. Frame rate 15–20 Hz.
Tracking:	Polhemus Fastrak for tracking hand and mouse.
Navigation:	Division, Ltd. 3-D mouse. Forward movement accomplished by pressing a left thumb button; backward movement using a right thumb button.
Object manipulation:	Objects can be touched by virtual hand and grabbed using trigger button on mouse.
Virtual world:	3-D chessboard placed on a table in a realistic garden setting (an open field also containing a chair, a tree, and small plant) with a sky dome, or suspended in a void. Self-representation as virtual hand. Garden texture mapped. Total garden scene 7,732 triangles, 6,276 in plain environment.
Training:	Introduction to 3-D chess given in real world. Training in moving and selecting objects conducted in a VE similar to that used in the study.
Experimental task:	Initiate game by pressing red button near chessboard. When a chess piece changes color, touch this piece and watch its movement. Press red button again to repeat moves until participant is confident he/she can remember which pieces move and to where they move, and can later reproduce final state of the board on a real 3-D chessboard.
Participants:	24 participants; 16 males. Some had prior VE experience.
Study design:	Between-subjects.
Presence measures:	Multi-item Questionnaire including 3 items related to presence.
Person-related meas.:	Spatial Awareness Test, *gender*, *chess experience*.
Task-related measures:	Practice, viewing time, level of nausea, confidence (that moves were remembered, correctly reproduced).
Performance measures:	Number of correct moves.
Findings: (1)	Visual display had a significant effect on presence, with HMD users reporting more presence.
(2)	Scene realism had no significant effect on presence.
(3)	For immersed participants, the Spatial Awareness Test scores had a significant negative relationship with presence.
(4)	Presence had no significant relationship with task performance.
(5)	*Visual display had a significant effect on performance, with improved performance found for the immersive display.*
(6)	*Scene realism had a significant effect on performance, with improved performance found for the realistic setting.*
(7)	*Chess experience and amount of virtual practice had significant positive effects on performance.*
(8)	*Gender had a significant effect on performance, with improved performance found for male participants. For females, Spatial Awareness Test score had a significant positive correlation with performance*.

[Slater 1995a] Slater, M., M. Usoh, and A. Steed. 1995. "Taking Steps: The Influence of a Walking Technique on Presence in Virtual Reality." *ACM Transactions on Computer-Human Interaction*, 2(3), 201–219. Also discussed in Slater (1994).

Factors:	Navigation (walking-in-place, 3-D mouse).
Computing platform:	Division, Ltd. ProVision 200 system.
Visual display:	Stereoscopic, color Virtual Reality Flight Helmet with 360 × 240 pixels per eye, FOV 75° H. Frame rate ~ 15 fps.
Tracking:	Polhemus sensors for tracking head and mouse.
Navigation:	Movement by pressing a button on Division, Ltd. 3-D mouse, with direction controlled by pointing or walking-in-place technique.
Object manipulation:	Division, Ltd. 3-D mouse used for grasping objects by intersecting the virtual hand with an object and pulling the trigger button.

Virtual world:	A corridor with a door leading to a room containing a chasm over another room 20 ft. below, with a wide ledge around the room. Self-representation as virtual body.
Experimental task:	Pick up an object, take it into a room, and place it on a chair placed on the far side of a chasm.
Participants:	16 participants from university campus. No prior VE experience.
Study design:	Between-subjects.
Presence measures:	Multi-item Questionnaire including 3 items related to presence. Observation of whether participants moved around the ledge or across chasm.
Task-related measures:	Rating of degree of nausea, extent of association with virtual body.
Findings: (1)	Navigation had a significant effect in that walking-in-place increased presence for participants who associated with their virtual body.
(2)	Path taken over chasm significantly associated with lower presence.
(3)	Association with virtual body had a significant positive correlation with presence for walkers only.
(4)	Reported nausea had a significant positive effect on presence.

[Slater 1995b] Slater, M., M. Usoh, and Y. Chrysanthou. 1995b. "The Influence of Dynamic Shadows on Presence in Immersive Virtual Environments." In *Proc. 2nd Eurographics Workshop on Virtual Reality*, 31 January–1 February, Monte Carlo. 8–31.

Factors:	Dynamic shadows (shadows for red spears, no shadows).
Computing platform:	Division, Ltd. ProVision system with dVS Version 0.3, Gouraud shading.
Visual display:	Flight Helmet HMD with 360 × 240 pixels per eye, FOV 75° H. Frame rate without shadows 9 Hz, with shadows 6–8 Hz.
Audio display:	Real radio.
Tracking:	Head-tracking.
Navigation:	Pressing center thumb button on Division, Ltd. 3-D mouse for forward movement in direction of gaze.
Object manipulation:	Press left button on Division, Ltd. 3-D mouse to fire a spear. Spear moves in direction determined by hand orientation until button released (then spear cannot be reactivated). Press right button to act as "infrared" radio switch. Additional button used to select objects.
Virtual world:	Virtual room 10 × 6 m. Five red spears near one wall, positioned with 10-cm variation behind a screen. Virtual radio positioned immediately in front of screen. Red square on floor positioned 3 m in front of screen. Four point light sources on wall facing red spears (used for dynamic shadows condition). Fixed target on wall at 90° to wall with red spears. Green spear that, without shadows, moves at mean velocity 92 cm/sec., with shadows at 47 cm/sec. Spears cast shadows that reflect their movement. Self-representation as virtual body. Total scene 413 triangles.
Training:	Practice-run in VE with experimenter talking participant through experimental task.
Experimental task:	Move to red square, face red spears, and select spear nearest to wall. Move to selected spear, pick it up, return to red square, and turn to face target on far wall. Orient spear on target and launch spear, guiding it with hand movements. Stop spear the instant it reaches the target. Then take green spear to red square. Meanwhile, when radio starts, point to it and use "infrared" switch to turn it off.
Participants:	8 participants from a university campus.
Study design:	Within-subjects.
Presence measures:	6-item SUS Questionnaire. Pointing to the position of a radio (switching on/off) when position of radio in real world differed from that in the virtual world.
Person-related meas.:	Personal representation system (visual, auditory, kinesthetic) and perceptual position (exocentric, egocentric) Neurolinguistic Programming (NLP) assessment.
Performance measures:	*Selection of correct spear, accuracy in estimating distance from target center and distance from wall.*

Findings:	(1)	Dynamic shadows had a significant positive effect on presence, as measured by the reported and objective behavioral measures for participants dominant in the visual sense.
	(2)	Reported presence had a significant positive correlation with objective behavioral measure of presence.
	(3)	*Dynamic shadows had a significant effect only on distance to wall performance measure, with use of dynamic shadows resulting in less error*.

[Slater 1995c] Slater, M., C. Alberto, and M. Usoh. 1995c. "In the Building or Through the Window? An Experimental Comparison of Immersive and Non-Immersive Walkthoughs." In *Proc. Virtual Reality Environments in Architecture*, 2–3 November, Leeds, UK. Also discussed in Usoh (1996).

Factors:	Visual display (HMD, desktop), color (VE matched to real location, matched to incorrect real location), elapsed time (same day visit to test building, 24 hr. later).
Computing platform:	Division, Ltd. ProVision 100 system. VE modeled using AutoCAD.
Visual display:	Flight Helmet HMD with 360 × 240 pixels per eye, FOV 75° H. TV screen used for nonimmersive condition (HMD placed on swivel chair in front of participant to use same method of setting viewpoint).
Tracking:	Polhemus Fastrasks for tracking head and mouse.
Navigation:	Forward movement accomplished by pressing left thumb button on Division, Ltd. 3-D mouse; backward movement by pressing right thumb button.
Object manipulation:	None.
Virtual world:	Representation of Computer Science Department in a building. Self-representation as 3-D arrow cursor.
Training:	Participants were shown how to navigate through the virtual building.
Experimental task:	Search for a plant but only go through open doors. Then in a real building, visit 2 locations and select which location matches the one in the VE. Then, in the matching location, find the plant (in same location as in VE). Participants stayed in each type of environment for about 15 min.
Participants:	24 participants recruited from a university campus; 12 males. 2 had prior VE experience.
Study design:	Between-subjects.
Presence measures:	6-item SUS Questionnaire. Additional question relating to "sense of having been there before."
Person-related meas.:	10-item NLP questionnaire.
Performance measures:	Time to find plant in VE and real building; accuracy of selection of matching locations in VE and real world.

Findings:	(1)	Visual display, color, and elapsed time each had no significant effect on presence.
	(2)	Ratio of time to find plant in real world to time in virtual world had a negative correlation with presence for a participant dominant in the auditory sense.
	(3)	*Visual display, color, and elapsed time had no significant effect on either performance measure*.

[Slater 1994] Slater, M., M. Usoh, and A. Steed. 1994. "Depth of Presence in Virtual Environments." *Presence*, 3(2), 130–144.

Factors:	Stacking type (transported between environments by donning virtual HMD, going through doors) and stacking depth (2, 4, 6), gravity (present, absent), virtual actor (following subject, staying in one position), visual cliff (present, absent).
Computing platform:	Division, Ltd. ProVision 200 system.
Visual display:	Virtual Reality Flight Helmet with resolution 360 × 240 pixels, FOV 75° H. Frame rate 7–16 Hz. Subject standing, able to walk within range determined by trackers.
Tracking:	Polhemus sensors for head-tracking and 3-D mouse (sampling rate 30 Hz).

Navigation:	Navigation by pressing middle button on Division, Ltd. 3-D mouse, with direction determined by the direction in which the hand is pointed. Movement with constant velocity or a single small step can be made by a single button click.
Object manipulation:	Object selection using Division, Ltd. 3-D mouse trigger.
Virtual world:	Initial scene consisting of empty room with cupboard and 12-in. cube. Subsequent scenes: (1) typical living room with sofas, table, TV; (2) abstract scene with randomly scattered cubes of difference sizes/colors; (3) typical office setting with desks, swivel chairs, computer, and filing cabinet; (4) kitchen with cupboards and cooker; (5) bar and bar furniture; (6) cliff with plank across a lower-level room with sofa, table, and chair. Self-representation as virtual body. Sound to mark transition between levels when using virtual HMD, also light touch on participant's back.
Training task:	In initial scene, practice how to move, pick up objects, and open cupboard doors for up to 5 min.
Experimental task:	Scenario based on a mixture of *Excalibur* and *Beauty and the Beast*. Task to find a set of swords, embedded in stone or hidden in the environment, and pull out the 1 sword that could be moved. Find a nearby well and drop the sword down the well. The Beast was awakened when the correct sword was found.
Participants:	23 participants from a university campus.
Study design:	Between-subjects.
Presence measures:	Multi-item Questionnaire with 3 items relating to presence. Observation of whether participant moved real body to match virtual body.
Person-related meas.:	11-item NLP Questionnaire.
Findings: (1)	Stacking depth had a significant effect on presence, with a positive relationship when using an HMD and negative when transported via doors.
(2)	Focus on visual or kinesthetic representation systems had a significant positive association with presence; focus on auditory representation system had a significant negative association with presence.
(3)	Gravity, virtual actor, or visual cliff had no significant effect on presence.
(4)	Aligning real and virtual bodies had no significant correlation with subjective presence.

[Slater 1993] Slater, M. and M. Usoh. 1993. "The Influence of a Virtual Body on Presence in Immersive Virtual Environments." In *Proc. 3rd Annual Conference on Virtual Reality*, 34–42.

Factors:	Self-representation (virtual body, arrow cursor).
Computing platform:	Division, Ltd. ProVision 200 system.
Visual display:	Flight Helmet HMD with 360 × 240 pixels per eye, FOV 100° H × 60° V. Frame rate 8–16 fps.
Audio display:	HMD headphones.
Tracking:	Two Ascension Technologies Flock of Birds used for tracking of head and mouse.
Navigation:	Forward movement accomplished by pressing left thumb button on Division, Ltd. 3-D mouse; backward movement by pressing right thumb button. Move in direction of pointing.
Object manipulation:	Selection of objects using mouse trigger.
Virtual world:	Corridor showing 6 doors on the left-hand side. A cube was positioned in the middle of the corridor. Room 1 contained everyday objects that might be found in an office. Room 2 contained various objects that would fly toward the subject at body level. Room 3 held a set of different colored blocks. Room 4 contained objects that would fly toward the subject's face. In Room 5, standard floor and ceiling patterns (and the virtual body when present) were reversed. Room 6 consisted of a chessboard with 2 pieces and a plank over a chasm that contained another chessboard about 18 ft. below. Sound cues when an object is grabbed, or a door opens.

Training:		Once in VE, told how to operate navigation controls. Then instructed to walk to far end of corridor and then back to cube and instructed how to pick cube up. Move cube around and drop it.
Experimental task:		Visit each room. In Room 1, navigate to the other side of the room, stop, and then return back to corridor. In Room 3, build a pile using all the blocks. In Room 6, pick up a chess piece and drop it over the edge of the plank onto the lower chess-board. Total time ranged from 13 to 27 min.
Participants:		17 graduate students studying human computer interaction.
Study design:		Between-subjects.
Presence measures:		6-item SUS Questionnaire. Observation of reaction to situations of relative danger.
Person-related meas.:		NLP assessment. Self-rating of adaptation to new environments.
Task-related measures:		Loss of realism as indicated in responses to open-ended questions.
Findings:	(1)	Self-representation had a significant positive effect on reported presence, with increased presence reported for a virtual body.
	(2)	Focus on visual senses significantly positively associated with increased presence; focus on auditory senses negatively associated with presence.
	(3)	For participants with a virtual body, focus on kinesthetic senses significantly positively associated with presence. For those without a body, focus on kinesthetic senses negatively associated with presence.
	(4)	Participants who mentioned problems with a loss of realism (things do not behave realistically) had significantly lower presence.
	(5)	Considered separately, reaction to height and reaction to flying objects had no relationship with subjective presence, but a reaction to either was more likely to occur for a lower sense of presence.
	(6)	Participants self-rated as fast adapters to new environments reported a lesser sense of presence.

[Snow 1996 (1)] Snow, M.P. December 1996. *Charting Presence in Virtual Environments and Its Effects on Performance*. Ph.D. Dissertation, Virginia Polytechnic and State University (Virginia Tech). Blacksburg, VA.

Factors:	Update rate (8, 12, 16 Hz), display resolution (320 × 200, 640 × 480), FOV (48° H × 36° V, 36° H × 27° V, 24° H × 18° V).
Computing platform:	2 Pentium PCs, Superscape VRT software with collision modeling.
Visual display:	Monoscopic VR4 HMD with FOV and resolution varying across experimental conditions. Viewpoint and eye level set at participant's standing eye level. Viewpoint attached to invisible body that measured 16.5 in. front-to-back and side-to-side. Participants standing at a swiveling platform.
Audio display:	HMD headphones.
Tracking:	Ascension Technologies Flock of Birds for head-tracking.
Navigation:	Logitech Magellan 6 DOF control device (3 DOF disabled) resting on platform.
Object manipulation:	Standard mouse resting on platform. Left-click to interact with objects beneath the cursor.
Virtual world:	Rooms connected by corridors with left and right turns and an elevator. Floors with checkerboard pattern, walls 8 ft. high with narrow vertical stripes every 5 ft. , ceilings with horizontal light panels every 10 ft. , corridors 3 ft. wide. One room with desk, chair, filing cabinets, wall-mounted vertical rack of open bins, clock on wall, 2 other rooms with fewer objects. Self-representation as arrow cursor. No texture mapping.
Training:	Pen-and-paper practice in magnitude estimation. Guided walk-through and demonstration of each task. One practice trial for each task.
Experimental task:	5 tasks: distance estimation of moving target (40 ft. and less), bins task, moving through corridors, detect moving target, choose static target. Average total time 2.5 hr.
Participants:	12 participants; age range 16 to 42; mean age 22 yr.

Study design: Within-subjects.
Presence measures: Magnitude estimation as ratio-scale measure of presence.
Task-related measures: Time spent in VE.
Performance measures: Locomotion time to complete and number of errors, distance estimation accuracy, bins task response time, moving target response time, choice response time.

Findings:

(1) Update rate, display resolution, and FOV had a significant positive effect on presence.

(2) Time spent in VE had a significant positive effect on presence.

(3) Time to complete and errors made in turns task and time to complete search task had a significant negative correlation with presence, but time to complete bins task and time to complete choice task had no significant correlation.

(4) Update rate had a significant negative effect on time to complete turns task and choice performance but had no significant effect on distance estimation accuracy, time to complete bins task, errors made during turns task, and search performance.

(5) Display resolution had a significant negative effect on distance estimation accuracy and search performance but had no significant effect on time to complete bins task, errors made during turns task, time to complete turns task, and choice performance. The interaction between display resolution and FOV had a significant effect on search performance.

(6) FOV had a significant negative effect on distance estimation accuracy and search performance but had no significant effect on time to complete bins task, errors made during turns task, time to complete turns task, and choice performance.

[Snow 1996 (2)] Snow, M.P. December 1996. *Charting Presence in Virtual Environments and Its Effects on Performance*. Ph.D. Dissertation, Virginia Polytechnic and State University (Virginia Tech). Blacksburg, VA.

Factors: Audio cues (auditory feedback when subject bumped into objects and clicked on interacting objects; context-appropriate sounds; none), texture mapping (textures applied to doors, walls, bins, and other objects; none), head-tracking (present, absent), stereopsis (present, absent), virtual personal risk (rear elevator doors missing, doors present).

Computing platform…

Performance meas.: As in [Snow 1996 (1)], except Visual Display employed FOV 48° H × 36° V, resolution 640 × 480; and update rate fixed at 8 Hz.

Findings:

(1) Sound, texture mapping, head-tracking, and stereopsis had a significant positive effect on presence.

(2) Virtual personal risk and time spent in VE had no significant effect on presence.

(3) Errors made in locomotion task had a significant negative correlation with presence, but time to complete the bins, turns, search, and choice tasks had no significant correlation.

(4) Audio cues had no significant effect on distance estimation, time to complete bins task, time to complete turns task, time to complete search task, and choice performance.

(5) Texture mapping had a significant effect on distance estimation but had no significant effect on time to complete bins task, errors in turns task, time to complete turns task, time to complete search task, and choice performance. An interaction between audio cues and texture mapping also had a significant effect on errors in turns task.

(6) Head-tracking had a significant effect on errors in turns task, time to complete turns task, and time to complete search task but had no significant effect on distance estimation, time to complete bins task, and choice performance. An interaction between texture mapping and head-tracking also had a significant effect on time to complete bins task.

(7) *Stereopsis had a significant effect on distance estimation but had no significant effect on time to complete bins task, errors in turns task, time to complete turns task, time to complete search task, and choice performance. An interaction between audio cues and stereopsis also had a significant effect on distance estimation and time to complete bins task.*

(8) *Virtual personal risk had a significant effect on errors in turns task and time to complete search task but had no significant effect on distance estimation, time to complete bins task, time to complete turns task, and choice performance.*

[Snow 1996 (3)] Snow, M.P. December 1996. *Charting Presence in Virtual Environments and Its Effects on Performance*. Ph.D. Dissertation, Virginia Polytechnic and State University (Virginia Tech). Blacksburg, VA.

Factors: Level of interaction (6, 12, 18 interactions possible), second user (present, absent), detail (low, medium, high).

Computing platform…

Performance meas.: As in [Snow 1996 (2)].

Findings:

(1) Level of interactions possible and level of detail had no significant effect on presence separately but had a significant interaction effect.

(2) Second user had a significant positive effect on presence, as did the interaction between environmental detail and number of interactions.

(3) Time in VE had a significant positive effect on presence.

(4) Time to complete bins, turns, and search tasks and errors made in turns task had a significant negative correlation with presence, but time to complete the choice task had no significant correlation.

(5) *Level of interaction, second user, and level of detail had no significant effect on any performance measure.*

[Steed 1999] Steed, A., M. Slater, A. Sadagic, A. Bullock, and J. Tromp. 1999. "Leadership and Collaboration in Shared Virtual Environments." In *Proc. IEEE Annual Virtual Reality International Symposium*, 13–17 March, Houston, TX.

Factors: Visual display (HMD, desktop).

Computing platform: SGI Onyx with twin 196-MHz R10000, Infinite Reality graphics, and 192 MB of main memory. SGI Indigo with a 200-MHz R4400 processor, High Impact graphics, 192 MB of main memory. SGI Octane with a 195-MHz R10000, 128 MB of main memory. dVS and audio server. Integrated Services Digital Network (ISDN) connection. Dive 3.2 software.

Visual display: Virtual Research VR4. Two desktop monitors.

Tracking: Two Polhemus Fastraks for tracking HMD and 3-D mouse.

Navigation: Immersive participant moved in direction of gaze at constant velocity by pressing button on 3-D mouse with 5 buttons. Desktop participants moved using a standard mouse with 3 buttons.

Virtual world: Model of actual laboratory where study took place. Includes a virtual room that had sheets of papers displayed around the walls. Each sheet had several words in a column, each preceded by a number. The words across all sheets with a common number combined to form a saying. Each participant represented by a basic DIVE avatar, differing only in color (red, green, blue), only visible to immersed (Red) participant.

Training: Learning to move through the environment. 4–5 min.

Experimental task: Group of 3 strangers meet in the VE and locate the room with puzzle. Figure out what puzzle is and then unscramble as many sayings as possible. 15-min. time

		limit. Don jacket the same color as avatar and, after answering a 10-min. questionnaire, meet other participants outside the matching real room. Enter real room and continue task for about 15 min.
Participants:		20 groups of 3 participants (data unavailable for 8 of these participants).
Study design:		Between-subjects.
Presence measures:		6-item SUS Questionnaire, 8-item Co-presence Questionnaire.
Task-related measures:		7-item Accord Questionnaire.
Findings:	(1)	Visual display had no significant effect on presence and co-presence.
	(2)	Presence had a significant positive relationship with co-presence.
	(3)	Accord had a significant positive relationship with co-presence.

[Stevens 2002] Stevens, B., J. Jerrams-Smith, D. Heathcote, and D. Callear. 2002. *Putting the Virtual Into Reality: Assessing Object-Presence With Projection-Augmented Models*. University of Portsmouth, UK.

Computing platform:		166-MHz Pentium PC with 40 MB of RAM.
Visual display:		3M MP8725 LCD projector, 800 × 600 resolution, 52 × 38 cm total image array projected on an A1 sheet of white paper. Participants seated in darkened room.
Audio display:		None.
Navigation:		Standard mouse.
Object manipulation:		Standard mouse.
Projected model:		Microsoft Paint. Physical model consisted of a white, plaster-covered polystyrene representation of a mobile telephone approximately 4× size of conventional mobile phone.
Training:		3-min. practice task using the drawing package projected onto a flat white surface.
Experimental task:		Design a color scheme for a mobile telephone case directly on the model's surface. 15-min. time limit.
Participants:		16 participants; 8 males; age range 22 to 39; mean age 29 yr. Computer literate but without experience in drawing packages.
Presence measures:		Object Presence Questionnaire (OPQ).
Person-related meas.:		Witmer-Singer ITQ, age, gender, drawing application competency, design type.
Task-related measures:		Task completion time.
Findings:	(1)	Task completion time had no significant correlation with OPQ Total or any OPQ subscales.
	(2)	Total ITQ scores had no significant correlation with OPQ scores. For males, ITQ Focus subscale had a significant positive correlation with OPQ Total and Involvement/Control and Natural subscales, and ITQ Involvement subscale had a significant positive correlation with OPQ Involvement/Control subscale. For females, ITQ Total and Games subscale had a significant negative correlation with OPQ Natural subscale, and ITQ Involvement subscale had a significant negative correlation with OPQ Involvement/Control subscale.
	(3)	Age, gender, drawing application competency, and design type had no significant correlation with OPQ Total or any OPQ subscales.
	(4)	*Age and gender had a significant correlation with ITQ Games subscale only. Drawing application competency and design type had no significant correlation with ITQ Total or any ITQ subscales.*
	(5)	*Task completion time had no significant correlation with ITQ Total or any ITQ subscales.*

[Tang 2004] Tang, A., F. Biocca, and L. Lim. 2004. "Comparing Differences in Presence During Social Interaction in Augmented Reality versus Virtual Reality Environments: An Exploratory Study." M.I.N.D. Labs, Michigan State University.

Factors:		Environment type (augmented reality, virtual reality).
Computing platform:		Software developed using ImageTclAR.

Visual display:	Stereoscopic Sony Glasstron LDI-100B HMD.
Tracking:	Head-tracking using Intersense IS-900 tracker.
Augmented environ.:	Black room where a set of virtual cell phones are presented on a physical table, with a partner across the table (played by an experimenter).
Virtual world:	Representation of augmented environment, with avatar representing partner.
Experimental task:	Carry out social discussion with partner about personal preferences about 2 cell-phone models.
Participants:	16 undergraduates; 11 males. No prior experience with virtual reality/augmented reality (VR/AR).
Study design:	Within-subjects.
Presence measures:	ITC-SOPI.
Findings: (1)	Environment type had a significant effect on ITC-SOPI scores, with more spatial presence reported by participants in the augmented reality condition.

[Thie 1998] Thie, S. and J. van Wijk. 1998. "A General Theory on Presence." In *Proc. 1st Inter. Workshop on Presence*, Ipswich, UK. Available at http://www.cs.ucl.ac.uk/staff/m.slater/BTWorkshop/KPN/.

Factors:	Social presence manipulation (choose avatar, choose nickname, personal information provided, trace other participants, gestures, moderator, know who said/did what, 3-person audio connection; none).
Computing platform:	4 multimedia PCs running NT and Win '95. Software included Netscape Navigator 3.01, Blaxxun Cyberhub, and Passport multi-user clients/servers.
Visual display:	Desktop monitors.
Object manipulation:	None.
Virtual world:	Shared Virtual Environment (SVE).
Training:	Practice with the SVE.
Experimental task:	Decision-making tasks.
Participants:	48 participants; 24 males. Experienced in Internet browsing, no prior experience with similar experiment.
Study design:	Between-subjects.
Presence measures:	Psotka's 21-item Virtual Presence Questionnaire and Thie's Social Presence Questionnaire, extremity of decision made, come-back rate.
Person-related meas.:	Psotka's 15-item Susceptibility for Presence questionnaire.
Findings: (1)	Social presence manipulation had no significant effect on social or virtual presence or extremity of decision making but did significantly increase come-back rate.
(2)	Social virtual presence had a significant positive correlation with virtual presence.
(3)	Come-back rate had a significant positive correlation with virtual presence but had no significant relationship with social virtual presence.
(4)	Susceptibility for presence had no significant correlation with virtual presence.

[Tromp 1998 (2)] Tromp, J., A. Bullock, A. Steed, A. Sadagic, M. Slater, and E. Frecon. 1998. "Small Group Behavior Experiments in the COVEN Project." *IEEE Computer Graphics*, 18(6), 53–63. Also discussed in Steed (1999).

Factors:	Avatar realism (realistic, basic), visual display (HMD, monitor).
Computing platform:	UCL machines SGI Onyx with twin 196-MHz R10000 processors, Infinite Reality graphics, 192 MB of main memory; SGI Indigo with a 200-MHz R4400 processor and 64 MB of main memory; audio server. Nottingham machine SGI Indigo with a 200-MHz R4400 processor, High Impact graphics, 192 MB of main memory. Fraunhofer Institut für Integrierte Schaltungen (IIS) machine SGI Octane with a 195-MHz R10000 and 128 MB of main memory. dVS/dVISE 5.0 and Rat software. ISDN connections with mean round trip times overall all trials being 100 ms between Nottingham and UCL, 450 ms between Nottingham and IIS, and 300 ms between UCL and IIS.

Visual display:	Virtual Research VR4, resolution 742 × 230 pixels/eye, FOV 67° diagonal, with 85% overlap, 170,660 color elements. 2 desktop monitors with 21-in. screen. Frame rate 20–30 Hz on all machines. Latency ~ 120 ms.
Tracking:	Polhemus Fastrak for head and mouse tracking.
Navigation:	5-button mouse or keyboard arrow keys.
Object manipulation:	None.
Virtual world…	
Experimental task:	See [Slater 2000b].
Participants:	4 groups of 3 participants from a university campus.
Study design:	Between-subjects.
Presence measures:	Presence questionnaire, Co-presence Questionnaire.
Task-related measures:	7-item Group Accord Questionnaire.
Findings: (1)	Avatar realism had no significant effect on presence.
(2)	Visual display had no significant effect on presence or co-presence.
(3)	Co-presence had no significant correlation with presence.
(4)	Group accord had a significant positive correlation with co-presence but had no significant correlation with presence.

[Uno 1997] Uno, S. and M. Slater. 1997. "The Sensitivity of Presence to Collision Response." In *Proc. IEEE 1997 Virtual Reality Annual International Symposium*, 1–5 March, Albuquerque, NM. 95–103.

Factors:	Collision response where realism of collisions manipulated using elasticity (1.0, 0.7), friction (0.7, 0.0), shape (ellipsoid, true shape).
Computing platform:	Division, Ltd. ProVision100.
Visual display:	Virtual Research Flight Helmet HMD, with 360 × 240 pixel resolution/eye, FOV 75° H × 40° V.
Tracking:	Polhemus Fastrak for head and mouse tracking.
Navigation:	Move by pressing button on Division, Ltd. 3-D mouse.
Object manipulation:	Objects grabbed using trigger button on 3-D mouse.
Virtual world:	Self-representation as virtual hand.
Experimental task:	Two games of pin bowling, with one collision parameter changed between games.
Participants:	18 students and other college staff; 12 males.
Presence measures:	6-item SUS Questionnaire.
Task-related measures:	1 question on experience of dizziness, sickness, or nausea.
Findings: (1)	Elasticity and shape had no significant effect on presence. Friction had a significant effect, positive with correct shape and negative with elasticity.
(2)	Prior VR experience had a significant negative effect on presence.
(3)	Simulator sickness had a significant negative effect on presence.

[Usoh 2000] Usoh, M., E. Catena, S. Arman, and M. Slater. 2000. "Using Presence Questionnaires in Reality." *Presence*, 9(5), 497–503.

Factors:	Environment type (virtual, real).
Computing platform:	SGI Onyx with twin 196-MHz R10000, Infinite Reality graphics, 192 MB of main memory.
Visual display:	VR4 HMD with resolution of 742 × 230 pixels per eye, FOV 67°D at 85% overlap, 170,660 color elements. Frame rate ≥ 20 Hz. Latency ~ 120 ms.
Tracking:	Two Polhemus Fastraks for tracking head and mouse.
Navigation:	Move through environment in direction of gaze while pressing thumb button on 5-button, 3-D mouse.
Object manipulation:	None.
Virtual world:	University research lab. Total scene 12,564 polygons.
Experimental task:	Search for a red box hidden in an office space. 7–14 min. in the virtual office, 6–10 min. in the real office.

Participants: 20 university students; 15 males.
Study design: Between-subjects.
Presence measures: 32-item Witmer-Singer PQ Version 2.0, 6-item SUS Questionnaire.
Task-related measures: Subjective rating of task performance.
Performance measures: Time to complete task.
Findings:
(1) Environment type had no significant effect on PQ and SUS presence totals but had a significant effect on 2 items on SUS Questionnaire, with users of the RE reporting more presence.
(2) SUS Questionnaire scores had no significant correlation with PQ Total scores for the virtual world but did have a significant positive correlation for the real-world condition.
(3) Task performance had no significant correlation with either Witmer-Singer PQ scores or SUS Questionnaire scores.
(4) Self-rating of task performance had no significant correlation with SUS questionnaire and PQ scores.

[Usoh 1999] Usoh, M.K.A., M.C. Whitton, R. Bastos, A. Steed, M. Slater, and F.P. Brooks Jr. 1999. "Walking > Walking-in-Place > Flying in Virtual Environments." In *Proc. Computer Graphics Annual Conference*, Los Angeles, CA. 359–364.

Factors: Navigation (walking-in-place, push-button-fly, real walking).
Computing platform: SGI Onyx2 with 1 graphic pipe, four 195-MHz R10000 processors, 2 GB of main memory. Scene rendered using OpenGL and locally developed software.
Visual display: Virtual Research V8 HMD with (640 × 3) × 480 pixels per eye, FOV 60°D at 100% overlap, aspect ratio 4:3. Radiosity lighting, texturing for half the polygons. Frame rate 30 Hz stereo. Overall system latency 100 ms.
Tracking: Custom optical wide area tracking, 10 × 4 m, latency 25 ms, head and one hand.
Navigation: For push-button-fly, used a joystick with locomotion in direction of gaze. Lag 500 ms for walking-in-place.
Object manipulation: Using joystick.
Virtual world: 5 × 4 m training room and 5 × 4 m pit room, connected by a door. Training room contained some chairs, a blue box, a green box. Pit room has 0.7-m ledge 6 m above the floor of the room, with a chair positioned on the ledge on the side of room opposite the door. Floor below populated with living room furniture. Self-representation as virtual body. Total 40,000 polygons.
Training: Participants practiced locomotion and picking up the blue box until they felt comfortable with both.
Experimental task: Pick up green box in training room and carry it to the chair in the pit room.
Participants: 44 participants; 28 males. 11 participants had VE prior experience.
Study design: Between-subjects.
Presence measures: 3-item SUS Questionnaire, 7-item SUS Questionnaire, Behavioral Presence Questionnaire (covering reported indicator or awareness of background noises in lab, rating of the similarities between reaction when looking down over pit vs. expected real-world reaction, rating of vertigo looking down over pit, rating of willingness to walk out over pit, path taken to chair).
Person-related meas.: Gender, game playing experience.
Task-related measures: Degree of associated with virtual body.
Findings:
(1) Navigation had a significant effect on 7-item SUS scores, with real walkers reporting more presence than walking-in-place users, who reported more presence than push-button-fliers. When oculomotor discomfort is considered, there was no significant difference between real walking and walking-in-place, but these groups reported significantly more presence than push-button-fliers. There was no significant difference for the expanded SUS Questionnaire.
(2) Navigation had no significant effect on 3-item SUS scores or behavioral measures of presence.

(3)	Degree of association with virtual body had a significant positive relationship with 3-item and 7-item SUS scores and behavioral measures of presence.
(4)	3-item SUS scores had a significant positive correlation with behavioral measures of presence.
(5)	Gender had a significant relationship with 3-item SUS scores, with females reporting more presence.
(6)	Game playing had a significant negative relationship with 3-item and 7-item SUS scores but had no significant correlation with behavioral presence.

[Usoh 1996] Usoh, M., C. Alberto, and M. Slater. 1996. *Presence: Experiments in the Psychology of Virtual Environments*. Department of Computer Science, University College London, UK.

Factors:	Detail (realistic with colored and textured objects, monochrome objects with no texture), agents (people standing by desks, no people).
Computing platform:	Division, Ltd. ProVision 100 system.
Visual display:	Flight Helmet HMD with 360 × 240 pixels per eye, FOV 75° H.
Tracking:	Head-tracking.
Navigation:	Using mouse.
Object manipulation:	Touching computer with virtual hand.
Virtual world:	Laboratory in Computer Science Department (Room V127). Included accurate representation of color and placement of desks, chairs, computers, cabinets, and floor space. Virtual people in the form of cardboard cutouts.
Training:	Familiarization with virtual world by navigating through it.
Experimental task:	Move through virtual world and switch on 6 computers, being automatically transported back to starting position after each computer switched on. Then go back and touch computers previously switched on (without being transported after each touch).
Participants:	16 students and college staff. 8 participants had desks in Room V127, 8 unfamiliar with Room V127.
Study design:	Between-subjects.
Presence measures:	Multi-item Questionnaire including 3 items related to presence. Observation of socially-conditioned behaviors and conventions.
Person-related meas.:	NLP assessment.
Findings: (1)	Level of detail and agents each had no significant effect on observed behavior.
(2)	For participants unfamiliar with Room V127, auditory representation mode had a significant negative correlation with presence.

[Väljamae 2004] Väljamae, A., P. Larsson, D. Västfjäll, and M. Kleiner. 2004. "Auditory Presence, Individualized Head-Related Transfer Functions, and Illusory Ego-Motion in Virtual Environments." In M. Alcaniz and B. Rey (Eds.), *7th Annual International Workshop: Presence 2004*. Valencia, Spain: Universidad Politecnica de Valencia. 252–258.

Factors:	HRTF (individualized, generic), sound rotation velocity (60 º, 20º per sec.), number concurrent sound sources (3, 1), distractors (present, absent).
Computing platform:	HRTFs measurement system designed by Chalmers Room Acoustic Group.
Computing platform:	Acoustic simulations rendered offline in CATT-Acoustic v 8 using Walkthrough Convolver.
Visual display:	None.
Auditory display:	Beyerdynamic DT-990Pro circumaural headphones driven by an NAD amplifier.
Tracking:	None.
Navigation:	None.
Object manipulation:	None.
Virtual world:	Marketplace in Tübingen, Germany, with binaural simulations of a virtual listener standing in one place and rotating a certain number of laps. 3 still sound sources

		used were a bus on idle, a small fountain, and a barking dog. Participant seated on an ordinary chair placed on an electronically controllable turntable.
Training:		None.
Experimental task:		Verbally report direction of motion.
Participants:		12 participants; 5 males; mean age 24 yr. Normal hearing verified by a standard audiometric procedure.
Presence measures:		1-item rating.
Task-related measures:		*Vection intensity rating, vection convincingness rating, count of ego-motion experiences.*
Findings:	(1)	HRTF had a significant effect on presence, with individualized HRTFs yielding more presence than generic HRTFs.
	(2)	Velocity and number of sound sources had no significant effect on presence.
	(3)	For single sound source condition only, distractors had a significant effect on presence, with more presence reported when distractors were present.
	(4)	*HRTFs and velocity had no significant effect on vection intensity or convincingness. Sound sources had a significant effect, with more vection reported for multiple sources.*

[Vinayagamoorthy 2004] Vinayagamoorthy, V., A. Brogni, M. Gillies, M. Slater, and A. Steed. 2004. "An Investigation of Presence Response Across Variations in Visual Realism." In M. Alcaniz and B. Ref (Eds.), *7th Annual International Workshop: Presence 2004.* Valencia: Universidad Politecnica de Valencia.

Factors:		Texture quality (nonrepetitive, repetitive), character realism (texture-mapped face, cartoon-like).
Computing platform:		Trimmension ReaCTor Cave-like system using SGI Onyx2 with eight 300-MHz R12000 MIPS processors and 4 Infinite Reality2 graphics pipes. DIVE and 3-D Studio MA X software, with PIAVCA for virtual character control.
Visual display:		Cave with three 3 × 2.2 m walls and 3 × 3 m floor. CrystalEyes stereo glasses.
Navigation:		Using joystick.
Object manipulation:		None.
Virtual world:		An urban street lined with buildings on either side and a few secondary streets. Textures (~ 40 or 20) used on billboards and fronts. 16 H-Anim-compliant characters with animated walks moved up and down the street, with only 8 visible at any one time.
Training:		Training to understand BIPs concept. Practice in moving in a virtual training room.
Experimental task:		After training, exit from training room on the street where told to do as the participant pleased for a few minutes. Signal "transitions to real" by pressing a button on the joystick. Returned to lab by leaving street through a door back to the training room.
Participants:		40 participants.
Study design:		Between-subjects.
Presence measures:		*1 item on presence*, BIPs, 5-item SUS Questionnaire and 6-item ITC-SOPI, heart rate variability (HRV). *1 item on co-presence*.
Person-related meas.:		Computer game experience.
Task-related measures:		Perceived realism of street, perceived visual and behavioral realism of characters, perceived expressiveness of characters, level of reported interaction with characters.
Findings:	(1)	Texture quality and character realism had a significant effect on presence questionnaire scores. Also, texture quality and character realism had a significant interaction, with less presence reported for repetitive texture quality and texture-mapped face.
	(2)	Texture quality and character realism had no significant effect on number of BIPs or changes in heart rate.
	(3)	Perceived behavioral realism of characters had a significant positive association with presence.

(4) Computer game experience had a significant positive association with presence questionnaire scores.
(5) Adjusted number of BIPs had a significant negative association with presence questionnaire scores.
(6) Perceived realism of street, perceived visual realism of characters, perceived expressiveness of characters, level of reported interaction with characters had no significant association with PQ scores.
(7) Number of BIPs had a significant negative association with change in heart rate.

[Vinayagamoorthy 2002 (1)] Vinayagamoorthy, V. 2002. *Bender Behavior: Posture & Emotion*. First Year Viva. UCL, London.

Computing platform: SGI Onyx2 with eight 300-MHz R12000 MIPS processors, 8 GB RAM and 4 Infinite Reality2 graphics pipes for ReaCTor system. SGI Onyx with twin 196-MHz R10000, Infinite Reality graphics and 192 MB of main memory for HMD system. DIVE software. Systems connected over Internet2, with round-trip times ~ 80–90 ms.
Visual display: ReaCTor with 3 × 2.2 m walls and 3 × 3 m floor, CrystalEyes stereo glasses, frame rate 45 Hz. Virtual Research V8 HMD, with 640 × 480 × 3 color elements/eye, FOV 60° diagonal at 100% overlap.
Tracking: Head and hand tracking using Intersense IS900 with stereo glasses and UNC HiBall Tracker.
Navigation: Walking in actual space, plus using handheld 4-button joystick in ReaCTor system. Using 5-button joystick in HMD system.
Virtual world: Large, open space with simple building in middle. Stretcher on ground outside building. Avatars represented as block-like structures with movable head and pointer indicating position of participant's tracked hand.
Training: Practice in navigating, lifting and carrying in a different virtual world to that used for the experimental task.
Experimental task: Meet with a partner (experimenter) and negotiate on lifting a stretcher together. Then carry stretcher along a blue path into a building and put it down on a red colored area inside the building. 5–8 min. allowed, depending on stage reached. Experimenter behaved as either very happy or very depressed.
Participants: 19 students; 14 males; age range 19 to 34.
Study design: Between-subjects.
Presence measures: 6-item Co-presence Questionnaire.
Task-related measures: Assessment of self and partner's performance, rating of similarity of task to that in real life, ratings of harmony and cooperation between partners, *rating of partner's mood*.
Findings:
(1) Co-presence had a significant positive relationship with assessment of self performance and assessment of partner's performance.
(2) Co-presence had a significant positive relationship with rating of harmony.
(3) Co-presence had a significant positive relationship with rating of cooperation.
(4) Co-presence had a significant positive relationship with rating of similarity of task to real experience.
(5) Co-presence had a significant negative relationship with rating of how participant hindered other participant in carrying out the task.

[Waterworth 2001] Waterworth, E., J. Waterworth, J. Holmgren, T. Rimbark, and R. Lauria. 2001. "The Illusion of Being Present: Using the Interactive Tent to Create Immersive Experiences." In *Proc. 4th International Workshop on Presence*, 21–23 May, Philadelphia, PA.

Factors: Film content (concrete, abstract).
Visual display: Interactive Tent with domed projection screen above prone participant.

Audio display:	3-D sound.
Tracking:	Head position and body movement.
Navigation:	None.
Object manipulation:	None.
Virtual world:	Illusion of Being designed to transport participant between states of excitement and calmness and between modes of presentation that elicit thought or direct sensory experiences. Taken through cycles of elements: snow, fire, earth, water. Moving head up or down for experience in a more concrete, perceptual, or abstract version. Moving head right or left determines whether what is experienced is captured from reality or is purely synthetic. Four versions: filmed events with natural soundtrack; text, sketches, and spoken words describing events; detailed virtual world with synthesized sounds; and wireframe 3-D with text labels and stylized synthetic sound effects.
Experimental task:	View 4 sets of 4 film clips of different durations (23, 50, 77, 104 sec.).
Participants:	16 students; 15 males; age range 20 to 40 yr.
Study design:	Within-subjects.
Presence measures:	8-item IPQ.
Task-related measures:	Estimation of film duration.
Findings: (1)	Film content had a significant effect on presence, with more presence reported for concrete content.
(2)	Film content had a significant correlation with presence only for 1 of 4 films (wireframe).
(3)	*Film content had no effect on duration*.

[Welch 1999] Welch, R.B. 1999. "How Can We Determine if the Sense of Presence Affects Task Performance?" *Presence*, 8(5), 574–577.

Factors:	Audio cues (screeching of tires, no cues).
Visual display:	HMD.
Experimental task:	Control a virtual car and attempt to collide with various cubes while avoiding others.
Study design:	Within-subjects.
Presence measures:	Presence rating scale (1–100%).
Performance measures:	*Number of collisions with cubes in a fixed period of time.*
Findings: (1)	Audio cues had a significant effect on presence, with more presence reported for use of tire sounds.
(2)	*Audio cues had no significant effect on task performance*.

[Welch 1996 (1)] Welch, R.B., T.T. Blackmon, A. Liu, B.A. Mellers, and L.W. Stark. 1996. "The Effects of Pictorial Realism, Delay of Visual Feedback, and Observer Interactivity on the Subjective Sense of Presence." *Presence*, 5(3), 263–273.

Factors:	Scene realism (high scene detail, low scene detail), level of interaction (driver, passenger).
Computing platform:	SGI 4D/120 GTXB graphics workstation.
Visual display:	Monitor with horizontal GFOV 62.5°, 1280 × 1024 pixels, stereoscopic viewing using Stereographics Corp. CrystalEyes shutter glasses. Nominal IPD 6.5 cm. Subject seated with viewing distance of 0.75 m, FOV ~ 27°. Curtain drawn around subject for isolation from rest of laboratory.
Navigation:	Steering wheel and foot-operated accelerator and brake pedals to control the car's direction and speed.
Object manipulation:	None.
Virtual world:	In high realism condition, blue sky, hilly road surface and surround, green background, red farm houses, oncoming cars, and guard posts. In low realism condition,

		black sky, flat road surface and surround, black background, no peripheral objects, no oncoming cars.
Training:		Two pairs of practice-runs.
Experimental task:		Drive a simulated car as quickly and smoothly as possible through a lap of a winding road. When a passenger instead of a driver, count the number of oncoming cars.
Participants:		20 optometry students, laboratory staff, and engineering graduate students; 9 males; mean age 27.2 yr.
Study design:		Within-subjects.
Presence measures:		Paired comparison with rating of difference.
Findings:	(1)	Scene realism and level of interaction each had a significant effect on presence, with more presence reported for the high scene detail/driver condition than for the low scene detail/passenger condition.

[Welch 1996 (2)] Welch, R.B., T.T. Blackmon, A. Liu, B.A. Mellers, and L.W. Stark. 1996. "The Effects of Pictorial Realism, Delay of Visual Feedback, and Observer Interactivity on the Subjective Sense of Presence." *Presence*, 5(3), 263–273.

Factors:		Scene realism (high scene detail, low scene detail), latency (no additional delay, additional 1.5 sec. delay in visual feedback). (Standard delay 200–220 msec.)
Visual display…		
Presence measures:		As in [Welch 1996 (1)], except for Participants: 20 optometry students, laboratory staff, engineering graduate students; 9 males; mean age 23.4 yr.
Findings:	(1)	Scene realism and latency had a significant effect on presence, with more presence reported for high scene detail/no additional delay condition than for the low scene detail/additional delay condition.

[Whitelock 2000] Whitelock, D., D. Romano, A. Jelfs, and P. Brna. October 2000. *Perfect Presence: What Does This Mean for the Design of Virtual Learning Environments?* PLUM Paper No. 137. The Open University, Milton Keynes. UK. Also discussed in http://www.presence-research.org/Whitelock&Jelfs.html.

Factors:		Audio cues (present, absent), type of training (video, written script).
Computing platform:		PC-based. MTropolis software.
Visual display:		Desktop monitor showing 2 views: one from submarine; other plan view showing where submarine located.
Navigation:		Standard mouse used to move the submarine.
Virtual world:		Representation of the North Atlantic Ridge. Supported with movies of geological features, flora, and fauna that illustrate probe functions.
Training:		Either viewed prerecorded video of using application or read script containing same instructions used in the video. 30 min. time limit.
Experimental task:		Travel in submarine to the ridge at the bottom of the ocean and explore the terrain for geological structures and biological life in 7 major locations. 30-min. time limit.
Participants:		10 pairs of high school students; age range 16 to 17.
Study design:		Between-subjects.
Presence measures:		3-item presence questionnaire.
Task-related measures:		Rating of ease of task.
Performance measures:		*Pre- and post-test of learning.*
Findings:	(1)	Enhanced audio cues had a positive effect on presence.
	(2)	Ease of task had a positive correlation with presence.
	(3)	*Audio cues had no significant effect on conceptual learning.*
	(4)	*Type of training had no significant effect on performance.*

[Wideström 2000] Wideström, J., A.-S. Axelsson, R. Schroeder, A. Nilsson, and Å. Aeblin. 2000. "The Collaborative Cube Puzzle: A Comparison of Virtual and Real Environments." In *Proc. ACM Conference on Collaborative Virtual Environments*, San Francisco, CA. 165–171.

Factors:	Environment type (real, 5-sided Cave display, desktop).
Computing platform:	SGI Onyx2 Infinite Reality graphics with fourteen 250-MHz, MIPS R10000 processors, 2 GB RAM, 3 graphics pipes. SGI O2 with 1 MIPS R10000 processor, 256 MB RAM. DVise 6.0 software with SGI Performer renderer. Lake Huron 3.0 for audio.
Visual display:	3 × 3 × 3 m TAN 3-D Cube with projection on 5 walls (no ceiling), stereoscopic viewing using Stereographics Corp. CrystalEyes shutter glasses; frame rate at least 30 Hz. 19-in. monitor with frame rate at least 20 Hz.
Auditory display:	Using headsets.
Tracking:	Polhemus trackers attached to shutter glasses and hand.
Navigation:	In the Cave system: by moving around and gesturing with a DVise 3-D mouse. In the desktop system: by moving middle button with a standard 2-D mouse.
Object manipulation:	In the Cave system: blocks selected and moved by participant putting his hand into a virtual cube and pressing on a 3-D mouse button. In the desktop system: blocks selected by clicking on the block with the left button of the 2-D mouse and then moved by keeping right button pressed and moving the mouse; cubes rotated using a combination of the right mouse button and shift key.
Virtual world:	Empty room containing 8 blocks with 1 of 6 different colors on each side. Representation of self and participant using standard dVise avatars.
Experimental task:	Two participants cooperate to solve a puzzle by arranging blocks into a cube such that each side of the completed cube displays a single color. 20 min. time limit.
Participants:	44 pairs of participants; 53 males; age range 20 to 56; mean age 32 yr.
Study design:	Within-subjects.
Presence measures:	2-item presence questionnaire, 2-item Co-presence Questionnaire.
Task-related measures:	*3-item contribution to Task Questionnaire, 1 item on collaboration*.
Findings: (1)	Environment type had a significant effect on presence, with participants in the Cave display reporting more presence.
(2)	Environment type had no significant effect on co-presence.
(3)	Presence had a significant correlation with co-presence only in the desktop environment.
(4)	*Environment type had a significant effect on all contribution to task items, with higher contribution assigned to Cave display participant by both participants.*
(5)	*Environment type had no significant effect on rating of collaboration, with significantly more collaboration reported for the REs than for the VEs. Cave display and desktop conditions had no significant difference.*
(6)	*There was a significant order effect on collaboration score, such that participants with experience from the virtual task reported significantly more collaboration in the real world than in the virtual world, while there was no difference for participants who started with the real task and then performed the virtual task.*

[Wiederhold 2001] Wiederhold, B.K., D.P. Jang, M. Kaneda, I. Cabral, Y. Lurie, T. May, I.Y. Kim, M.D. Wiederhold, and S.I. Kim. 2001. "An Investigation Into Physiological Responses in Virtual Environments: An Objective Measurement of Presence." In G. Riva and C. Galimberti (Eds.), *Towards CyberPsychology: Mind, Cognitions and Society in the Internet Age*. Amsterdam, The Netherlands: IOS Press (2003).

Computing platform:	Intel microprocessor-based PC, with advanced audio and Diamond Monster-3-D graphics cards. Customized software.
Visual display:	Liquid Image MRG4 HMD. Subject seated.

Audio display:	Earphones on HMD, with vibratory sensations delivered by subwoofer mounted under chair.
Tracking:	Polhemus Insidetrak for head-tracking.
Navigation:	None.
Object manipulation:	None.
Virtual world:	Passenger cabin in an airplane with outside graphics.
Training:	None.
Experimental task:	View airplane flight as passenger seated in left window seat over the wing and looking out the left window. 6-min. flight.
Participants:	72 computer expo attendees; 30 males; age range 18 to 73; mean age 36.4 yr. 10 phobic based on the DSM-IV criteria.
Presence measures:	Reality Judgment and Presence Questionnaire, %Δskin resistance and %Δheart rate.
Person-related meas.:	TAS, DES.
Task-related measures:	*Kennedy SSQ*.
Findings: (1)	Presence had a significant positive correlation with realism, TAS, and DES. Realism also had a significant positive correlation with TAS and DES.
(2)	Percentage change of skin resistance and heart rate had a significant negative correlation with presence.
(3)	*SSQ score had a significant correlation with the DES but not with the TAS*.

[Wiederhold 1998] Wiederhold, B.K., R. Davis, and M.D. Wiederhold. 1998. "The Effects of Immersiveness on Physiology." In G. Riva et al. (Eds.), *Virtual Environments in Clinical Psychology and Neuroscience*. Amsterdam: IOS Press B.V. 52–60.

Factors:	Visual display (HMD, 3-D monitor).
Computing platform:	Intel microprocessor-based PC, with advanced audio and Diamond Monster-3-D graphic cards. Software from Previ (Spain), VRHealth (Italy), Hanyang University (Seoul, Korea), and Virtually Better (Atlanta, Georgia).
Visual display:	Liquid Crystal MRG4 HMD. Subject seated.
Audio display:	HMD headphones or speakers positioned next to monitor. Subwoofer mounted under participant's chair.
Tracking:	Polhemus Insidetrak for head-tracking.
Navigation:	None.
Object manipulation:	None.
Virtual world:	Passenger cabin in an airplane with outside graphics.
Experimental task:	View airplane flight as passenger seated in left window seat over the wing and looking out the left window. 10-min. flight.
Participants:	5 psychology doctoral-level students; 2 males; age range late 20s to 40s. No prior experience with VE. One participant had a fear of flying, meeting DSM-IV criteria for a specific phobia.
Study design:	Within-subjects.
Presence measures:	*Questionnaire*, Δskin resistance, Δheart rate, Δperipheral skin temperature, Δrespiration rate.
Findings: (1)	For nonphobic participants, visual display had a significant positive effect on Δskin resistance.
(2)	Visual display had no significant effect on Δheart rate, Δperipheral skin temperature, and Δrespiration rate.

[Wilfred 2004] Wilfred, L.M. 2004. *Learning in Affectively Intense Virtual Environments*. M.Sc. Thesis. University of Missouri – Rolla.

Factors:	Affective intensity (intense, neutral).

Computing platform:	2.8-GHz Pentium IV with 512 MB RAM. Virtual worlds developed using Half-Life game engine. Bopiac system to collect physiological data.
Visual display:	i-glasses SVGA-3-D HMD.
Tracking:	None.
Navigation:	Using 5-button mouse.
Object manipulation:	Using 5-button mouse.
Virtual world:	Two versions, one affectively intense and the other affectively neutral. Representation of computer science building at University of Missouri – Rolla. Intense world had explosions and fires starting randomly (within 0–25 sec. of each) around the participants' avatars. Both versions had dead and injured bodies generated randomly at 18 locations.
Training:	Conducted in two connected virtual rooms: one containing a fire extinguished and the other a fire. Used to gain familiarity with interface and controls.
Experimental task:	As first responder fire fighter, complete an inspection of the building to locate the dead and injured, while dealing with any situations that arose. 12 min. Then in real building, with audio tape replaying sounds of fires and explosions, locate rooms where dead and injured had been and make a note of these. Possible actions included setting off a fire alarm, picking up a fire extinguisher, putting out a fire.
Participants:	22 undergraduates.
Study design:	Between-subjects.
Presence measures:	5-item SUS Questionnaire.
Person-related meas.:	Gender, Affective Intensity Questionnaire, ITQ.
Task-related measures:	Δskin conductance.
Performance measures:	Count of dead and injured people.
Findings: (1)	Affective intensity had no significant effect on presence or Δskin conductance. Participants' affective intensity had no significant correlation with presence or Δskin conductance.
(2)	ITQ Games subscale had a significant positive correlation with presence. ITQ has no significant correlation with Δskin conductance.
(3)	Gender had no significant positive correlation with either presence or Δskin conductance.
(4)	Task performance had no significant correlation with either presence or Δskin conductance.
(5)	*Task performance had no significant correlation with participants' affective intensity. It had a significant correlation with gender only for the count of injured, with males performing better*.

[Witmer 1998 (2)] Witmer, B.G. and P.B. Kline. 1998. "Judging Perceived and Traversed Distance in Virtual Environments." *Presence*, 7(2), 144–167.

Factors:	Navigation (treadmill, joystick, passive teleportation), gender, distance cues (auditory tone every 10 ft. for every other segment, no cues), movement speed (1.2, 2.4 mph), texture density (2-ft., 4-ft. tiles), traversed distance (10, 40, 80, 120, 160, 200, 240, 280 ft.).
Computing platform:	SGI Crimson Reality Engine. VE modeled using Software Systems MultiGen and rendered using SGI Performer.
Visual display:	Fakespace Labs BOOM2C display fitted to participant's head using a head strap, used in monochrome mode, stereoscopic with 1280 × 1024 pixels per eye with 70° overlap, maximum FOV 140° H × 90° V.
Tracking:	Via BOOM2C.
Navigation:	Only forward movement permitted. Movement via treadmill, joystick, or by being passively teleported by the experimenter.
Object manipulation:	None.
Virtual world:	Four test routes, each consisting of a series of 8 connected hallway segments. Hallways 10 ft. wide, 10 ft. high, varied in length (20, 50, 90, 130, 170, 210, 250,

		290 ft.). Total length always 1,210 ft. Segments formed right angles with each other to form alternating series of left-right turns.
Training:		Follow a practice route in the VE twice, practicing procedures and movement (latter at two speeds).
Experimental task:		Traverse 4 test routes, reporting traversed distance and time taken for each segment.
Participants:		72 university students; 36 males; age less than 37 yr.
Study design:		Within-subjects for movement speed, texture density, and traversed distance, between-subjects for type of navigation, gender, and distance cues.
Presence measures:		32-item Witmer-Singer PQ Version 2.0.
Person-related meas.:		Gender.
Task-related measures:		*Rating of compellingness of movement.*
Performance measures:		*Accuracy of estimates of distance traveled, relative error for each segment/route.*
Findings:	(1)	Navigation had a significant effect on presence, with treadmill users reporting more presence than joystick or teleport users; who did not differ significantly.
	(2)	Gender had no significant effect on presence.
	(3)	Distance cues had no significant effect on presence.
	(4)	*Distance cues, movement speed, traversed distance, and 3 interactions (distance cues and movement speed, distance cues and traversed distance, movement speed and traversed distance) had a significant effect on estimates of segment distance traveled and relative error, but type of movement, texture density, and gender had no significant effect.*
	(5)	*Distance cues, movement speed, and gender had a significant effect on estimates of total route distance, but type of movement had no significant effect.*
	(6)	*Type of movement had a significant effect on compellingness, with higher ratings given for treadmill than joystick, and both these higher than for teleporting.*

[Witmer 1996] Witmer, B.G., J.H. Bailey, and B.W. Knerr. 1996. "Virtual Spaces and Real-World Places: Transfer of Route Knowledge." *International Journal of Human-Computer Studies*, 45, 413–428. Also discussed in Bailey 1994 (2).

Factors:	Training type (RE, VE, verbal directions, and photographs).
Computing platform:	SGI Crimson Reality Engine with single processor, 2 raster managers. Model generated using Software Systems MultiGen, rendered using Sense8 Corp. WorldToolKit.
Visual display:	Stereoscopic, 2-color Fakespace Labs BOOM2 with FOV 140° H × 90° V, 1280 × 492 pixels per eye. Update rate 30–60 Hz.
Tracking:	Head-tracking using BOOM2 display.
Navigation:	Using BOOM2 display, user moves in direction facing, or backwards, at a constant speed by depressing buttons on display control handles.
Object manipulation:	None.
Virtual world:	Large, spatially complex office building. Texture maps derived from photographs of objects.
Training:	None.
Experimental task:	15-min. study of route directions and photographs of landmarks for a complex route, either with or without a map. Then 3 rehearsals of route in the VE, in the actual building, or verbally. All participants required to stop at and identify 6 destinations along the route. All participants tested in actual building. Office building approximately 117,950 sq. ft. Complex route (1,500 ft.) wound along corridors on 3 floors leading to 6 destinations in 2 office suites; 41 directional changes and 47 two-choice decision areas along route. Building areas included typical office furnishings, including fluorescent lights, wall paintings, and exit signs. Model included functional staircases and out-of-the-window views. Doors to accessible areas automatically opened when approached.
Participants:	20 participants; 10 males.

Presence measures: 32-item Witmer-Singer PQ Version 2.0.
Person-related meas.: *29-item Witmer-Singer ITQ Version 2.0*, *gender*.
Task-related measures: Kennedy SSQ.
Performance meas.: Route knowledge assessed using number of attempted wrong turns, route traversal time, misidentified destinations, distance traveled. Building configuration knowledge measured using a target triangulation technique (projective convergence providing consistency, accuracy, average distance error, and average miss distance measures).

Findings:

(1) Route knowledge and configuration knowledge had no significant correlation with presence.
(2) Simulator sickness had a significant negative correlation with presence.
(3) During route rehearsal, type of rehearsal had a significant effect on route learning, with slower route traversal times and more wrong turns for VE group than for the other two groups, which were not significantly different.
(4) During route rehearsal, trial had a significant negative effect on route traversal time. Trial also had a significant interaction with type of rehearsal, such that the VE group showed a steeper learning curve with respect to route rehearsal time than the other two groups and, with respect to wrong turns, also a steeper learning curve than the symbolic group, which was steeper than that of the real group.
(5) For training transfer, type of rehearsal had a significant effect on route learning, with the real group making fewer wrong turns than VE group, who made fewer wrong turns and took less time than the symbolic group.
(6) For training transfer, type of rehearsal had a significant effect on route traversal time, with those in the real and VE groups taking less time than those in the symbolic group.
(7) Type of rehearsal had no significant effect on configuration knowledge.
(8) Configuration knowledge, as measured by accuracy and consistency on paper-based convergence test, had a significant negative correlation with ITQ scores.
(9) Gender had no significant effect on route learning but had a significant effect on configuration knowledge, with improved performance found for male participants.
(10) SSQ scores had no significant effect on route or configuration knowledge.
(11) Gender had no significant effect on SSQ scores.

[Witmer 1994a (1)] Witmer, B.G., J.H. Bailey, and B.W. Knerr. April 1994. *Training Dismounted Soldiers in Virtual Environments: Route Learning and Transfer*. U.S. Army Research Institute for the Behavioral and Social Sciences.

Factors: Training type (VE, building, symbolic), map (present, absent).
Computing platform: SG Crimson Reality Engine. Software Systems Multigen and Sense8 Corp. WorldToolKit by
Visual display: Fake Space Labs 2-color BOOM2 display.
Audio display: None.
Tracking: Via BOOM2 display.
Navigation: Via BOOM2 display.
Object manipulation: None.
Virtual world: Representation of first 3 floors of a building in the Central Florida Research Park, ~ 117,950 sq. ft. Many of the office furnishings were included in offices and work spaces. Doors to modeled areas opened automatically when within 10 ft. distance, and remained open for several seconds.
Experimental task: Study of designated route for 15 min., using step-by-step directions, landmark, and destination photos and, depending on condition, map with route marked. Followed by 3 route rehearsals in appropriate condition. Performance evaluated in a real-world transfer test, following the learned route and identifying 6 specified destinations along the route. Then participant taken to the lobby on third floor and

		asked to exit the building as quickly as possible using the most direct route. Third task required estimating direction and distance to 4 goal locations.
Participants:		60 college students; age range 18 to 53 yr.
Study design:		Between-subjects.
Presence measures:		Witmer-Singer PQ.
Person-related meas.:		*Gender*.
Task-related measures:		Kennedy SSQ.
Performance measures:		Number of wrong turns, number of misidentified destinations, time to reach each destination and entire route, number of steps taken along route. Also, time taken and distance traveled to exit building and, for location task, consistency, accuracy, average distance error, and average miss distance.
Findings:	(1)	Measures of route learning had no significant correlation with presence.
	(2)	Measures of configuration knowledge had no significant correlation with presence.
	(3)	SSQ scores had a significant negative correlation with presence.
	(4)	*Training type had a significant effect on route learning, with best performance for building training followed by VE training, with symbolic training worst. Map and gender had no significant effect on route learning.*
	(5)	*Training type and map had no significant effect on configuration knowledge, though males performed significantly better than females.*

[Witmer 1994b (1)] Witmer, B.G. and M.J. Singer. October 1994. *Measuring Presence in Virtual Environments*. Technical Report 1014. U.S. Army Research Institute for the Behavioral and Social Sciences.

Computing platform:		Two DX50 486-MHz PCs with Intel Action Media graphics boards. VE developed using Sense8 Corp. WorldToolKit.
Visual display:		Stereoscopic, color Virtual Research Flight Helmet HMD with FOV 83° H × 41° V, resolution 234 × 238 pixels per eye.
Tracking:		Polhemus Isotrak for head-tracking.
Navigation:		Using joystick or spaceball.
Object manipulation:		Using joystick or spaceball.
Virtual world:		VEPAB VE, (see Singer 1995).
Training:		Explanation and demonstration of operation of control device.
Experimental task:		Set of generic VEPAB tasks: Snellen Chart, color perception test, distance estimation, backing-up, hallway turns, figure 8 (∞) hallway, doorways.
Participants:		24 participants; 16 males; age range 17 to 37; mean age 24 yr.
Presence measures:		32-item Witmer-Singer PQ Version 1.0. Measured after two experimental sessions.
Person-related meas.:		29-item Witmer-Singer ITQ Version 1.0.
Task-related measures:		Kennedy SSQ.
Performance measures:		Time to complete and accuracy of response to each task.
Findings:	(1)	Accuracy for the windows task had a significant negative correlation with PQ Total and Control Responsiveness, Interface Awareness, and Control Distraction subscales. Accuracy for the bins task had a significant positive correlation with PQ Total and Control Responsiveness, Involvement, and Control Distraction subscales. Accuracy for the slide task had a significant positive correlation with PQ Total and Control Responsiveness, Sensory Exploration, and Involvement subscales. Accuracy for the dial task had a significant positive correlation with PQ Control Responsiveness and Involvement subscales. Accuracy for the choice reaction time task had no correlation with PQ Total or any subscales.
	(2)	Time to complete for the windows task had a significant negative correlation with PQ Total and Control Responsiveness, Interface Awareness, and Control Distraction subscales. Time for the bins task had a significant negative correlation with PQ Total and Control Responsiveness, Involvement, Control Distraction subscales. Time for the slide task had a significant negative correlation with PQ Total and all subscales. Time for the dial task had a significant negative correlation with PQ

Involvement subscale. Time for the choice reaction task had a significant negative correlation with PQ Total and Control Responsiveness, Sensory Exploration, and Involvement subscales. Time for the simple reaction time task had a significant negative correlation with PQ Total, Control Responsiveness, Sensory Exploration, and Involvement subscales.

(3) SSQ Total and all subscales had a significant negative correlation with the PQ Control Responsiveness subscale.

(4) PQ scores had no significant correlation with ITQ scores.

(5) *Performance had no significant correlation with ITQ Total.*

[Witmer 1994b (2)] Witmer, B.G. and M.J. Singer. October 1994. *Measuring Presence in Virtual Environments*. Technical Report 1014. U.S. Army Research Institute for the Behavioral and Social Sciences.

Computing platform…

Training: As in [Witmer 1994b (1)].

Experimental task: Set of generic VEPAB tasks: flying-through-windows, elevator, bins, slide/dial manipulation, simple/choice reaction time, stationary/moving target acquisition.

Participants…

Performance measures: As in [Witmer 1994b (1)].

Findings:

(1) Accuracy for the windows task had a significant negative correlation with PQ Total and Control Responsiveness subscale. Accuracy for the bins task had a significant positive correlation with PQ Sensory Exploration and Involvement subscales. Accuracy for the slide task had a significant positive correlation with PQ Total and Control Responsiveness and Sensory Exploration subscales. Accuracy for the dial task had a significant positive correlation with PQ Sensory Exploration and Involvement subscales. Accuracy for the choice reaction task had a significant positive correlation with PQ Total and Sensory Exploration subscale.

(2) Time to complete the windows task had a significant negative correlation with PQ Total and Control Responsiveness and Interface Awareness subscales. Time to complete the bins task had no significant correlation with PQ Total or any subscales. Time for the slide task had a significant negative correlation with PQ Total and Sensory Exploration subscale. Time for the dial and choice reaction tasks had no significant correlations with PQ Total or any subscales. Time for the simple reaction task had significant negative correlation with PQ Involvement subscale.

(3) SSQ Total had a significant negative correlation with PQ Total, Control Responsiveness, Sensory Exploration, and Involvement subscales. SSQ Nausea, Oculomotor, and Disorientation subscales had a significant negative correlation with PQ Control Responsiveness subscale. SSQ Nausea subscale had a significant negative correlation with PQ Sensory Exploration subscale. SSQ Oculomotor subscale had a significant negative correlation with and PQ Involvement and Control Distraction subscales.

(4) PQ scores had no significant correlation with ITQ scores.

(5) Performance had no significant correlation with ITQ Total.

[Youngblut 2004 (1)] Youngblut, C. 2004. *Experience of Presence in Virtual Environments*. IDA Document D-2960. Institute for Defense Analyses, Alexandria, VA.

Factors: Visual display (rear-projection screen, desktop, written procedures only).

Computing platform: 700-MHz Pentium III PCs with NVIDIA GeForce 3 graphics accelerators. Reality by Design, Inc. CHEM-BIO SVS2 software developed using SimStorm.

Visual display: Proxima 9260 rear projector with 9.5 × 7.5 ft. DA-LITE projection screen, enclosed in curtained-off area.

Audio display: Voice-activated radios for team communication, speakers for sounds of alarms.

Tracking:	Tracking of head (vertical motion only) and mock chembio monitor using Intersense Corp. IS-600 Series Precision Motor Trackers.
Navigation:	Using belt-mounted, custom 3-D joystick with rear-projection screen interface; table positioned Microsoft Sidewinder Precision Pro 6 DOF joystick with desktop interface.
Object manipulation:	Using joystick controls and mock-up chembio monitor.
Virtual world:	Three IDA Virtual Cities with submeter accuracy. One was a recreation of a warehouse on New York Pier 16, another was an office building in New York, the third was Penn Station. All included representative objects. No self-representation.
Training:	25-min. study of written procedures, followed by a 5-min. question-and-answer period. Participants in each VE group then received a 10-min. demonstration and practice of the immersive or desktop interface.
Experimental task:	VE participants also performed 2 practice missions to learn mission procedures for searching for chembio hazards in a designated area. 20 min. each. Performance evaluated in a real-world transfer test, 30 min. time limit.
Participants:	35 student intern employees; 27 males; mean age 21.
Study design:	Between-subjects.
Presence measures:	32-item Witmer-Singer PQ Version 1.0, 6-item SUS Questionnaire.
Person-related meas.:	29-item Witmer-Singer ITQ Version 1.0, gender, game experience, experience with immersive VEs, Ekstrom's cognitive tests (visualization aptitude using Paper Folding test, spatial orientation using Card Rotation and Cube Comparison tests, visual memory using Map Memory test, spatial scanning using Map Planning test).
Performance measures:	Sum of correctness and completeness scores for individual elements of mission procedures.

Findings:

(1) Visual display had no significant effect on presence, as measured using either the PQ or SUS Questionnaire (traditional or modified method of scoring).

(2) For rear-projection screen participants, PQ Total, PQ Involved/Control, and PQ Natural scores each had a significant positive correlation with SUS Questionnaire scores (modified method). For desktop monitor participants, PQ Natural scores had a significant positive correlation with SUS Questionnaire scores (traditional method). There was a significant positive correlation between the two methods of scoring the SUS Questionnaire for desktop monitor participants only.

(3) For rear-projection screen participants, game experience and VE experience had a significant positive correlation with SUS Questionnaire scores (traditional method). Spatial orientation (card rotations) also had significant positive relationships with PQ Total, PQ Involved/Control, and PQ Interface Quality scores. ITQ Involvement subscale had a significant negative correlation with PQ Interface Quality. Gender, visualization aptitude, spatial orientation (cube comparisons), visual memory, and spatial scanning ability had no relationship with PQ or SUS scores.

(4) For desktop monitor participants, spatial scanning and spatial orientation (cube comparisons) had a significant positive correlation with PQ Involved/Control scores, and visual memory had a significant positive correlation with PQ Interface Quality scores. For these participants, there were also significant positive relationships between ITQ (Total and all subscale scores) and the SUS Questionnaire (both traditional and modified methods). Gender, computer game experience, experience with immersive VEs, visualization aptitude, and spatial orientation (card rotations) had no relationship with PQ or SUS scores.

(5) For both VE groups together, SUS questionnaire scores (traditional method) had a significant positive correlation with performance. PQ scores had no correlation with performance.

(6) Visual display had a significant effect on performance, with participants in the VE groups achieving significantly higher mission scores.

[Youngblut 2004 (2)] Youngblut, C. 2004. *Experience of Presence in Virtual Environments*. IDA Document D-2960. Institute for Defense Analyses, Alexandria, VA.

Factors:	Visual display (rear-projection screen, desktop, paper-based).
Computing platform:	700-MHz Pentium III PCs with NVIDIA GeForce 3 graphics accelerators. Reality by Design, Inc. CHEM-BIO SVS2 software developed using SimStorm.
Visual display:	Proxima 9260 rear projector with 9.5 × 7.5 ft. DA-LITE projection screen, enclosed in curtained-off area.
Audio display:	None.
Tracking:	Tracking of head (vertical motion only) using Intersense Corp. IS-600 Series Precision Motor Tracker.
Navigation:	Using belt-mounted, custom 3-D joystick with rear-projection screen interface; table positioned Microsoft Sidewinder Precision Pro 6 DOF joystick with desktop interface.
Object manipulation:	Using joystick controls.
Virtual world:	Representation of the ground floor of an office building. This space was divided into 12 exterior offices, 4 interior offices, 2 small open areas, and 2 large, open areas, 1 of which contained another office. There were 2 exterior entrance doors to the building and 2 stairwells providing access to upper floors. The space was empty except for 8 objects. These objects were items of furniture, such as a desk, file cabinet, sofa, and snack machine. 6 objects were positioned in offices, and the remaining 2 objects were positioned in the open areas.
Training:	Participants in each VE group then received a 10-min. demonstration and practice of the immersive or desktop interface.
Experimental task:	Navigate freely through the office space to build spatial knowledge of the area. 3 sessions of 4-min. study of paper-based floor plan followed by 12 min. of virtual world navigation for the rear-projection screen and desktop participants.
Participants:	35 student intern employees; 21 males; mean age 21.
Study design:	Between-subjects.
Presence measures:	32-item Witmer-Singer PQ Version 1.0, 6-item SUS Questionnaire.
Person-related meas.:	29-item Witmer-Singer ITQ Version 1.0, gender, experience with video games and 3-D computer games, experience with immersive VEs, Ekstrom's cognitive tests (visualization aptitude using Paper Folding test, spatial orientation using Card Rotation and Cube Comparison tests, visual memory using Map Memory test, spatial scanning using Map Planning test).
Performance measures:	Distance and orientation to specific objects and room placement test immediately following third session. Room placement test repeated as retention test 1 week later.

Findings:

(1) Visual display had no significant effect on presence, using either the PQ or SUS Questionnaire.

(2) PQ and SUS Questionnaires results (scored both in the traditional and modified manner) showed a significant positive correlation for desktop monitor participants only. For desktop monitor participants only, there was a significant positive correlation between the two methods of scoring the SUS Questionnaire.

(3) For rear-projection screen participants, SUS Questionnaire scores (traditional and modified methods) showed a significant correlation with gender, with females reporting a greater sense of presence. For these participants, there was also a significant positive correlation between PQ Interface Quality and spatial orientation (card rotations) and PQ Interface Quality and visual memory, and a significant negative correlation between ITQ Total, ITQ Focus, and ITQ Involvement scores and SUS Questionnaire scores (traditional method) and between ITQ Focus scores and SUS Questionnaire scores (modified method). Computer game experience, experience with VEs, visualization aptitude, spatial orientation (cube comparisons), and spatial scanning ability had no relationship with PQ or SUS scores.

(5) For desktop monitor participants, there was also a significant negative relationship between SUS Questionnaire scores (traditional method) and spatial orientation (cube comparisons). ITQ scores, gender, experience with games, experience with immersive VEs, (visualization aptitude, spatial orientation (card rotations), visual memory, and spatial scanning had no relationship with PQ or SUS scores.

(6) Looking at both VE groups, the accuracy for distance estimation scores had a significant positive relationship with SUS Questionnaire scores (modified method). For rear-projection screen participants only, the accuracy for orientation and for distance estimation each had a significant positive correlation with PQ Total, PQ Natural, and PQ Interface Quality scores. For the same participants, the results of the retention test had a significant negative correlation with the SUS Questionnaire (modified method) and PQ Involved/Control scores.

(7) Visual display had no significant effect on the accuracy of estimating the orientation and distance of object locations, but participants using the rear-projection screen were significantly more accurate in the initial room placement test than those who only studied the paper-based floor plan. Participants using the rear-projection screen were significantly more accurate than those who used the desktop monitor in the room placement retention test, and both groups were significantly more accurate than participants who only studied the paper-based floor plan.

[Youngblut 2004 (3)] Youngblut, C. 2004. *Experience of Presence in Virtual Environments*. IDA Document D-2960. Institute for Defense Analyses, Alexandria, VA.

Factors: Visual display (HMD, desktop monitor).

Computing platform: 700-MHz Pentium III PCs with NVIDIA GeForce 3 graphics accelerators. Reality by Design, Inc. CHEM-BIO SVS2 software developed using SimStorm. Physiological data captured using the Thought Technologies, Inc. ProComp+ system.

Visual display: Proxima 9260 rear projector with 9.5 × 7.5 ft. DA-LITE projection screen, enclosed in curtained-off area.

Audio display: None.

Tracking: Tracking of head (vertical motion only) using Intersense Corp. IS-600 Series Precision Motor Tracker.

Navigation: Using belt-mounted, custom 3-D joystick with rear-projection screen interface; table positioned Microsoft Sidewinder Precision Pro 6 DOF joystick with desktop interface.

Object manipulation: Using joystick controls.

Virtual world: A small, third-world town with several open-fronted stores and other buildings along the main streets, and some cars on the road. The surrounding area was filled within identical mud huts.

Training: Participants in each VE group then received 10-minute demonstration and practice of the immersive or desktop interface.

Experimental task: Search for 7 stolen missiles in an urban setting while defending against hostile individuals. The missiles were positioned in plain sight. The participant was armed with a gun controlled by joystick buttons and used this gun to defend himself against hostiles. These hostiles were scripted to appear when a participant reached specified locations. Some moved toward the participant, and others moved through side streets parallel to or away from the participant. Each hostile fired on the participant when the participant came into that hostile's FOV. There were a total of 10 hostiles. If the participant was "killed," the visual display blanked for a couple of seconds, and then the participant could resume his/her search. 6 civilians also appeared at prescripted points in the scenario. Once the participant completed his/her search, he/she had to move to an armored vehicle positioned toward the outskirts of the town. 20-min. allowed to task.

Participants: 34 student intern employees; 20 males; mean age 22.5.
Study design: Between-subjects.
Presence measures: 32-item Witmer-Singer PQ Version 1.0, 6-item SUS Questionnaire, Δskin conductance, Δheart rate.
Person-related meas.: 29-item Witmer-Singer ITQ Version 1.0, gender, experience with video games and 3-D computer games, experience with immersive VEs, Ekstrom's cognitive tests (visualization aptitude using Paper Folding test, spatial orientation using Card Rotation and Cube Comparison tests, visual memory using Map Memory test, spatial scanning using Map Planning test).
Performance measures: Mission score calculated using the proportion of missiles found and hostiles killed, adjusted for the number of civilians killed by mistake and the number of times a participant "died."
Findings:

(1) Visual display had a significant effect on SUS Questionnaire results (scored in the traditional and modified manner) only, with desktop monitor participants reporting significantly higher presence.

(2) For HMD participants, PQ Interface Quality had a significant negative correlation with SUS Questionnaire results (traditional method). For desktop monitor participants, PQ Total and all subscales had a significant positive correlation with SUS Questionnaire scores (modified), and PQ Interface Quality had a significant positive relationship with SUS Questionnaire scores (traditional). Δskin conductance had a significant negative correlation with PQ Total and PQ Natural scores. Looking at both VE groups, the two methods of scoring the SUS Questionnaire scores had a significant positive relationship.

(3) For HMD participants, VE experience had a significant positive relationship with PQ Natural scores and a significant negative correlation with Δskin conductance, there was a significant positive relationship between computer game experience and Δheart rate and a significant negative correlation between spatial orientation (card rotations) and PQ Total and PQ Involved/Control scores. For desktop monitor participants, gender had a significant relationship with SUS Questionnaire scores (modified method), PQ Involved/Control, and PQ Natural scores. In all cases, females reported higher levels of presence. ITQ scores, visualization aptitude, spatial orientation (cube comparisons), visual memory, and spatial scanning ability had no relationship with PQ or SUS scores.

(4) Desktop monitor participants showed a significant positive relationship between VE experience and PQ Involved/Control scores. They also showed a significant negative correlation between ITQ Total and PQ Total and PQ Interface Quality scores, and a significant negative correlation between ITQ Involvement and PQ Total, PQ Involved/Control, PQ Natural, and SUS Questionnaire (modified method) scores. Gender, experience with computer games, visualization aptitude, spatial orientation, visual memory, and spatial scanning had no relationships with PQ or SUS scores.

(5) For desktop monitor participants only, there was a significant positive correlation between Mission score and PQ Interface Quality scores. No relationships were found for the SUS Questionnaire, Δskin conductance, or Δheart rate.

(6) Visual display had a no significant effect on mission score.

[Youngblut 2002] Youngblut, C. and B.M. Perrin. 2002. "Investigating the Relationship Between Presence and Task Performance in Virtual Environments." Presented at the *IMAGE 2002 Conference*, 8–12 July, Scottsdale, AZ.

Factors: Practice with interface (basic 2–3 min., extended additional 30 min).
Computing platform: SGI Reality Monster. DVise software.
Visual display: Virtual Research stereoscopic HMD, resolution 640 × 480, refresh rate 30 Hz. Participant standing, free to walk as necessary for task.
Audio display: Task statements prerecorded using Authorware on PC.

Tracking:		Ascension Technologies head and hand tracking.
Navigation:		Based on head movement.
Object manipulation:		3-D mouse button used for grasping objects.
Virtual world:		Aircraft hangar with an entire F/A-18 aircraft. Self-representation as virtual hand.
Training:		For basic practice, written description of task and interface, and 2–3 min. of familiarization with activities such as moving to an object and grasping and manipulating it. For extended practice, basic practice plus about 30 min. of practice on a task different to that used in the study.
Experimental task:		24-step F/A-18 maintenance procedure involving the removal and replacement of the wing high-level fuel valve. The procedure is performed inside an access area in the wing and involves both physical obstructions (parts that must be removed to get to the fuel valve) and visual obstructions (even after the physically obstructing parts are removed, several fasteners holding the fuel valve cannot be seen through the access door). One practice-run of the task in the VE, accompanied by verbal instructions. Training transfer tested on a physical mock-up.
Participants:		40 participants from Boeing staff; 27 males; age range 20 to 64; mean age 40 yr. No prior experience with aircraft maintenance.
Study design:		Between-subjects.
Presence measures:		32-item Witmer-Singer PQ Version 1.0, 6-item SUS Questionnaire.
Person-related meas.:		29-item Witmer-Singer ITQ Version 1.0, visualization aptitude using Paper Folding test, experience with relevant tools (e.g., fixing cars), age, gender, height, experience with video games and 3-D computer games, experience with immersive VEs.
Task-related measures:		Kennedy SSQ, rating of fatigue.
Performance measures:		Paper-and-pencil knowledge test, time to complete task on physical mock-up, count of performance errors while completing training transfer test.
Findings:	(1)	Practice with interface had no significant effect on SUS scores and had a significant positive effect only for PQ Interface subscale.
	(2)	The only personal characteristic that had a significant correlation with SUS Questionnaire scores was the ITQ Focus subscale, and this was a positive correlation.
	(3)	ITQ scores, age, gender, 3-D-computer game experience, and visualization aptitude had no significant correlations with PQ scores. Video game experience had a significant negative correlation with PQ Involved subscale. VE experience had a significant negative correlation with PQ Total and the PQ Involved subscale.
	(4)	SSQ scores and fatigue had no significant correlation with SUS Questionnaire scores.
	(5)	SSQ Oculomotor subscale had a significant negative correlation with PQ Total. SSQ Total and Oculomotor subscale had a significant negative correlation with PQ Involved subscale. Fatigue had a significant negative correlation with PQ Interface subscale.
	(6)	PQ Total and all subscale scores had a significant positive correlation with SUS Questionnaire scores.
	(7)	SUS and PQ Involved each had a significant negative correlation with count of performance errors.
	(8)	*Practice with interface had no significant effect on any performance measure.*
	(9)	*Experience with relevant tools and visualization aptitude had a significant positive effect on knowledge test scores and a significant negative effect on both training transfer tests. Gender had a significant effect on the knowledge test scores and time taken for the training transfer test, with males achieving higher test scores and females taking less time. Video game and 3-D computer game experience had a significant negative effect on time taken for the transfer test.*
	(10)	*SSQ and fatigue had no significant effect on any performance measure.*

[Zimmons 2003] Zimmons, P. and A. Panter. 2003. "The Influence of Rendering Quality on Presence and Task Performance in a Virtual Environment." In *Proc. IEEE Virtual Reality 2003 Conference*, 22–26 March, Los Angeles, CA. 293–294.

Factors:		Texture mapping (combinations of high/low texture resolution and high/low lighting quality plus additional condition of black and white grid texture).
Computing platform:		Rendering with ATI Radion 8500 with dual video outputs. Lightscape for lighting computations.
Visual display:		Virtual Research V8 HMD with 640 × 480 pixels per eye.
Auditory display:		None.
Physiological devices:		ProComp+ worn as backpack for heart rate and skin conductance measurement.
Tracking:		3rdTech, Inc. optical tracking system for head and hand tracking.
Navigation:		Using joystick.
Object manipulation:		Using joystick with trigger to pick up and drop objects.
Virtual world:		2-room virtual world, consisting of a training room and pit room.
Training:		Practice using VE interface in the training room, including picking up and dropping objects on a target.
Experimental task:		Drop 4 objects on targets in a virtual chasm.
Participants:		55 college-age participants; 25 males. No prior VE experience, no phobia of heights.
Presence measures:		SUS Questionnaire, Δheart rate, Δskin conductance.
Person-related meas.:		Gender, *Guilford-Zimmerman spatial orientation test*.
Task-related measures:		Kennedy SSQ.
Performance meas.:		*Accuracy of dropping balls on targets*.
Findings:	(1)	Texture mapping had no significant effect on any presence measure.
	(2)	Gender had no significant effect on presence.
	(3)	*Texture mapping had no significant effect on task performance.*
	(4)	*SSQ scores and height anxiety had no significant correlation with texture mapping but had a significant correlation with gender.*
	(5)	*Spatial ability had no significant correlation with task performance but had a significant difference for gender.*

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE: March 2006	2. REPORT TYPE: Final
3. DATES COVERED *(From–To)*	September 2003 – November 2003
4. TITLE AND SUBTITLE	What a Decade of Experiments Reveals about Factors that Influence the Sense of Presence
5a. CONTRACT NUMBER	DASW01-04-C-0003
5b. GRANT NUMBER	
5c. PROGRAM ELEMENT NUMBER	
5d. PROJECT NUMBER	
5e. TASK NUMBER	DA-2-2121
5f. WORK UNIT NUMBER	
6. AUTHOR(S)	Christine Youngblut
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	Institute for Defense Analyses 4850 Mark Center Drive Alexandria, VA 22311-1882
8. PERFORMING ORGANIZATION REPORT NUMBER	IDA Document D-3208
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)	DARPA 3701 Fairfax Drive Arlington, VA 22203
10. SPONSOR/MONITOR’S ACRONYM(S)	
11. SPONSOR/MONITOR’S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT	Approved for public release; distribution is unlimited. (18 December 2006)
13. SUPPLEMENTARY NOTES	

14. ABSTRACT

This report reviews the results of experiments that have examined the sense of presence experienced in virtual environments. It provides guidance about factors that have a good probability of manipulating presence and gives an idea of the scope of experimentation that has been performed. Over 170 experiments are identified, but the analysis focuses on those experiments that have been replicated (more or less) and on factors that have shown consistent results across studies.

15. SUBJECT TERMS

factors, presence, virtual environment

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
Uncl.	Uncl.	Uncl.	SAR	180	Robert Allen
					19b. TELEPHONE NUMBER *(include area code)*: 571-218-4527

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18